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PART II : PRESIDENTIAL ADDRESSES

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FORTY-SIXTH INDIAN SCIENCE CONGRESS

DELHI, 1959

Congress President
DR. A. L. MUDALIAR,
M.D., LL.D., D.Sc., D.C.L. (OXON), F.R.C.O.G., F.A.C.S.

PRESIDENTIAL ADDRESS

Ladies and Gentlemen,

I am beholden to my colleagues of the Indian Science Congress for giving me this unique privilege of presiding over its 46th Session. During these several years many distinguished scientists have adorned this chair and it is with no sense of false modesty that I confess that this honour is one which I did not look forward to nor did I ever anticipate. I have ventured to accept your invitation, however, because of the conviction that the honour is one that is meant more to my profession, the medical profession, which it has been my great privilege to practise for the last fifty years. From another point of view, I felt that it gave me an opportunity to pay my humble tribute to the great part that science has played in the progress of medicine within the last fifty years and to place before you the picture of how medical science has been influenced and guided by the great discoveries in the fields of the physical sciences, the biological sciences, the technical and technological sciences. Never has this influence been more dominant than during the past quarter of a century when phenomenal and significant progress has been achieved in every branch of medical science, thanks to the achievements of scientists in the sister sciences to which I have referred.

TRIBUTE TO BASIC SCIENCES

It is therefore with feelings of profound gratitude that, as a representative of the field of medical science, I pay my tribute to the great scientists who have made significant contributions in advancing the fields of knowledge of the basic sciences. I venture to express the hope that the medical sciences have also played some little part in stimulating those working in the fields of the allied sciences. It cannot but be otherwise. Discoveries in one field of science lead to repercussions in other fields of science and the problems of one scientific discipline always stimulate research in other disciplines of science. To-day therefore one is forced to the conclusion that science is indivisible, that no compartmentalism can possibly be conceived, that every new research in any field of the physical, biological or technological sciences has its effect on the others and that therefore the reactions in the minds of those who are investigating problems in any one of these sciences are considerable. At the same time, so enormous are the widening fields of research in these sciences that one may well be lost in the contemplation of the amount of knowledge that is being made available every year which cannot possibly be comprehended by any single individual unless opportunities are given to realise at least the fundamentals of the great discoveries in the several branches of science. From this point of view therefore it seems to me a very happy idea of the originators of the proposal to hold a Science Congress that they conceived the possibility of scientists interested in every branch of science meeting at a common session and exchanging thoughts and experiences. The platform for science, if it is to be utilised effectively and for good purpose, must in the main be a platform not only for recording new experiences, new discoveries and new trends in scientific thought but, what is equally important, it should be a platform for disseminating the knowledge that has been gained in the different branches thereof, alike to the votaries of the respective science as also in a large measure to everyone with a scientific bent and in the pursuit of scientific knowledge. It is thus that scientists will be able, with greater amount of success, to realise the way in which scientific discoveries could best be utilised and the manner in which problems in their own special fields could better be tackled with confidence. This will be made more obvious when I refer to the advances of medical sciences and the debt medical sciences owe to the discoveries in other fields, in the fields of physical sciences, biological sciences and technological sciences.

PROGRESS IN 20TH CENTURY

The 20th century has witnessed a remarkable progress in the field of scientific discoveries, so much so that science has for the first time come into its own. It may be asserted with confidence that far more scientific work has been done in the last 50 years than in the whole period of the previous history of humanity. Although many epoch-making discoveries have been made in the past, their application for practical purposes and the rapid development of the associated sciences has become a phenomenon of the 20th century, more than that of any other period. In the past, science was thought of as an accessory factor — interesting, occasionally exciting but perhaps not of much practical value. Few were prepared to consider that it had a direct bearing on the main stream of human endeavour and on the progress of historical events. The danger at present is the opposite, that of giving science too much credit, whether for good or evil, in the tremendous, vastly disturbing kaleidoscopic changes that are taking place consequent upon wars and revolutions, so unfortunately frequent in this half century. The power of science to affect the life of man for good or evil is no longer seriously in doubt. The problem now is rather that of finding the means by which science can be directed to constructive and not to destructive ends.

Perhaps in no fields of science could the constructive use of scientific discoveries be more clearly demonstrated than in the field of medical science. And it may be stated that it is only in this century that the influence of science on medical practice, derived from the 19th century pioneer work of Pasteur and others, began to make itself felt on a large scale. Medicine has increasingly become a dependent on the important chemical and instrument industries. Pharmacy, far from being a collection of simple herbs or the combination of drastic mineral salts, has become a scientific industry and one of no small importance even from the purely commercial point of view. No longer will the witches' cauldron portrayed in Macbeth be utilised even by the most ignorant of the population as a panacea for certain ills.

PREVENTION OF DISEASES

The outstanding development in medicine of the 19th century centres round the prevention of diseases. The discovery of bacteria in relation to the causation of diseases has naturally led to a large number of investigations as to the best methods of preventing the growth and development of bacteria in the human system. This in turn led to better methods of treatment and to the surgical skill which was made possible by the use of anaesthetics. The health of the individual and of the community has been improved beyond all expectation by the adoption of numerous laws enforcing public health measures and the 20th century opened its medical practice ready to co-operate with other branches of knowledge in the new role that science was destined to take in society.

One of the first responsibilities of a society is care for the health of its members. As has been already pointed out, during the opening decades of the 20th century, medical practice has made progress comparable with that achieved in other branches and. in the realm of public health, science has extended its interest to embrace every aspect of social life. Radium, X-ray and many electric treatments are witness to the influence of the new physics on medicine. The skill in surgery has been increased beyond all expectation and chemistry has added to the efficiency of antiseptic measures while one branch has produced important drugs capable of destroying some of the most harmful bacteria which took a heavy toll of life before.

MEDICINE AND WAR

Paradoxical as it may seem, it is the urgency for certain definite discoveries during a war that has led to a greater scientific effort in preventive and palliative medicine than had been possible during any period of peace. It was during the War that methods of creating blood banks and serum banks were first initiated and tried. To-day, lives of many thousands of persons have been spared because of these blood banks established in many a town in all civilized countries and largely contributed by voluntary donors. But the most spectacular event of the last War was the demonstration of the great potentialities of new drugs like Penicillin or insecticides like D.D.T. It was in 1928 that Fleming made the observation that some of his bacterial cultures were being eaten away at various spots in the petridishes in which they were prepared and noted that this was due to a mould which had grown there and which seemed to be giving out some substance which killed the bacteria. It was not however till 10 years later that Florey and Chain started a systematic search for natural antibiotics, when Fleming's observation was put to use. By the time the clinical value of Penicillin was proved, the War came and gave a great impetus for further investigations. It was a concentrated effort in the fields of chemistry, biology and medicine that led to the great use of this wonder drug, as it was called, to save literally thousands of lives.

The discovery of Penicillin is often quoted as an example that important discoveries come by chance. It is no doubt true that some great discoveries do come by chance. But chance is multiplied by providing opportunities for discovery in the first place and for development by interested people in the second. Once Penicillin was discovered, it was relatively easy to search through nature for other substances which might have the same or better effects. Thus a whole new field of antibiotics was opened: Streptomycin, Aureomycin, Chloromycetin, Synermycin, Tetracycline, a bewildering array of antibiotics sometimes confusing and confounding to the medical practitioner.

During the Second World War, it was clearly realised that disease had played a much greater part in the previous wars than any of the destructive weapons of warfare and that therefore the most paramount consideration should be to protect the forces against disease, especially in the tropical regions where war was waged, as well as the realisation that the consequences of wounds should be minimised as far as possible. This led to an all-round advance in sanitational medicine and surgery.

NUTRITION

It was realised early in the 20th century that one of the most neglected aspects of medicine was that of dietetics. And as the science of nutrition leapt into prominence, the study of the problems of nutrition and of nutritional disorders led to major scientific discoveries of the accessory food factors, the Vitamins. This naturally led to further investigation as to what kind of food people needed and how much to keep them healthy and alive. This in turn had a direct influence on the largest and most ancient industry, agriculture, and on the newly established food industries. Agriculture, far from being the major human traditional occupation, is rapidly being transformed into an industry which is becoming more and more scientific in character: while in the field of medicine, an attempt at a scientific control of human conditions is being undertaken so that, in future, health and not disease will be the chief concern. In view of the large concentration of the population in urban areas, it will be easily realised that the food needed for them can no longer come straight from the farm to the table. There is also the danger that adulterated foods and improperly prepared food-stuffs may result in great calamities on account of food poisoning. It has therefore become necessary in most countries to have stringent laws passed to observe rigid control over the production and distribution of food-stuffs. This has led to research and development in the science of preparing and preserving food; thus artificial refrigeration, hermetically sealed food production, pasteurisation, sterilisation and other scientific methods have now become the common means of ensuring supply of safe food-stuffs.

ROLE OF VITAMINS

In the past, many diseases were attributed, and quite rightly, to deficiencies in diet. Of these perhaps the most important was Scurvy, the dreaded disease of sailors. But the study of those accessory factors so essential in food, the Vitamins, gave an immediate impetus to the study of biochemistry and at last chemicals, that could be used and issued immediately for curative purposes in the shape of Vitamins, were discovered. Some of them are simple as Vitamin C, Ascorbic Acid, but others like Vitamin B are found to contain several different substances, each needed for carrying out some different function in the body. Science thus enabled us to possess the means of ensuring a healthy life as far as food could do it for the population of the whole world if only the will to take advantage of the discoveries of science were there. Yet it is unfortunate that to-day diseases due to Vitamin deficiency such as Rickets, Scurvy, Beri-Beri and Pellagra are common in different parts of the world, either due to ignorance or poverty. And it is here that international organizations such as the Food and Agricultural Organization of the United Nations are doing much and can do a good deal more in this direction. It may be of interest to know that paradoxically enough the civilian population of many European countries, which were in the grip of the Great War, were actually kept in better health during the War in spite of reduced gross diet because of a scientific approach to the qualitative contents of such diet ignoring the quantitative factor. It is needless to say that the health and activity of the armies in the field were likewise ensured by attention to these nutritive factors.

ROLE OF HORMONES

Of equal importance for the maintenance of health were minute quantities of substances produced inside the body itself by organs such as ductless glands. These were known as the hormones. And to-day a study of hormones is a most entrancing study and promises to lead to great results. Prominent among these hormones are the aestrogenic and other ovarian hormones, Thyroxin and Insulin. Recent advances have shown the possibility of producing synthetic hormones or substitutes as in the case of diabetes. The original impetus for biochemical research came from medicine. Ever since Pasteur discovered bacteria, there was always the hope that some chemical substances could be found that would kill the bacteria without adversely affecting the patient. The first success was arrived at by trying to see that chemicals that would colour bacteria for recognition purposes could also be used to destroy them. This was how the group of chemical substances known as Sulphonamides were produced in 1932 by Domagk who was awarded the Nobel Prize but was not permitted to accept it.

MEDICINE AND THE PHYSICAL SCIENCES

Medicine owes a great deal to the physical sciences as well. The developments in physics led to the invention of a number of new instruments. For a long time, the ordinary microscope was the only instrument powerful enough to view some of the small animalcules which would not be seen by the naked eye. The use of the electron microscope was a great advance in the field of microbiology. It enables us to see and reproduce on photographs the whole range of structure from those clearly visible in an ordinary microscope down to those of practically atomic dimensions. In the electron microscope, viruses and bacteriophages become visible and distinguishable for the first time and the finer nature of such tissues as muscle and skin begin to show something of why they have the peculiar and useful properties that they show in living organisms. The electron microscope can magnify up to 1 million times and thus a whole new biology is coming into existence by the use of this instrument. Besides the electron microscope, some new modifications of the ordinary microscope have been made, stimulated by the competition of the electron microscope. The most important of these modifications are the phase and interference microscopes which enable cells to be studied alive when previously they had to be killed and stained. Next came the new ultra-violet and infrared reflecting microscopes which brought out details not otherwise visible and could also be used to study the chemical composition of cell structure.

The progress of medical science has always depended on the perfection of precision instruments of observation and control. Until very recently, these were not developed for the immediate needs of biology. The most recent and most powerful adjuncts to biological study have also come from physics — the valve amplifier to measure the minute currents and potentials in living system, the electron microscope referred to already and the use of isotopes and tracer elements which promises an interpretation of the actual process of transformation of chemicals in living systems. These and the electro-encephalograph for registering the drug reactions of the human brain have led to the coming of age of biophysics. This does not mean that biochemistry has become less important. In fact, the post-war period is witnessing a multiplication of antibiotic drugs and a rational approach to that large field of hormone therapy and pharmacology.

Radio isotopes have been used in the field of industry, biology biochemistry and medicine. Leaks in water mains and pressurised cables can be located by adding small amounts of radio active materials which can be detected when they escape. Radio isotopes are proving indispensable in biochemistry for example. Penicillin has been made active and its movement observed in the body of animals. Great progress has also been made in the treatment of surface cancers. Such examples make us realise that we are only at the beginning of the development of the utilisation of radio isotopes.

HAZARDS OF RADIATION

When Roentgen, then an obscure Professor at Wurzberg, first discovered X-rays in 1895, he little realised that this was a scientific discovery of great potentiality. The use of X-rays in the field of medicine is well known to-day, whether in the diagnostic or therapeutic processes, and consequently the medical profession has studied for long the dangerous ill effects of radiation and the remedial measures by which people working in such plants should be protected. In the 20th century however a great figure — one of the greatest figures of the 20th century physical science — emerged in the person of Lord Rutherford. His discovery has, as is now known, been rapidly followed up in various fields by a large number of scientific workers in all parts of the globe.

PROGRESS OF SCIENCE IN INDIA

Although sporadic attempts were made now and then to establish institutes of science for the fostering of research in some fields, yet it must be confessed that very little was accomplished owing to the great lack of well equipped laboratories and incentives for scientific workers.

The whole picture has changed however after the dawn of Independence in this country. The Council of Scientific and Industrial Research was the spearhead to promote the starting of a large number of national laboratories for various scientific disciplines. The first of these laboratories were the National Physical Laboratory and the National Chemical Laboratory but separate laboratories have since been established for researches, both basic and applied, in several fields of scientific knowledge. To-day, there are a large number of these laboratories spread over the length and breadth of this country. The work of these national laboratories covers a very wide field indeed. The laboratories afford excellent facilities for research with the most modern techniques and every attempt is being made to link up research with the problems of industry, so vital for the progress of our country. Besides the establishment of these national laboratories, a great step has been taken forward to encourage young men with scientific talents to pursue a career in science untramelled by any considerations of other avenues of employment. Many have been awarded foreign scholarships through Government and through various organizations to acquire modern techniques in the fields where such techniques have not yet been fully developed in our own country. Yet the attractions of other services like the administrative services, wherein a very large number of posts have been created, draw away some of the best among the graduates in science who thus are lost to science for ever. It may be interesting to know that in ancient days Roman Engineering ranked with Roman Law in importance. The Emperor, Constantine, wrote in the 4th century: "We need as many engineers as possible. As there is a lack of them, invite to this study persons of about 18 years who have already studied the necessary sciences. Relieve the parents of taxes and grant the scholars sufficient means." The appropriateness of similar measures being adopted in India need hardly be emphasised.

NATIONAL PROFESSORSHIPS

The institution of National Professorships for the first time has been hailed with approval by all interested in the future of this country. We are happy that the first National Professor to be appointed was none other than our esteemed countryman, Dr. C. V. Raman, who is so actively engaged in his research work to-day. It is a matter of considerable satisfaction to all that two more eminent sons of India, Dr. Krishnan and Dr. Bose, past Presidents of the Indian Science Congress, have been recently appointed as National Professors. The worth of a great scientist can never be measured in terms of the marketplace. Speaking of Faraday, Tyndal says that he might, with ease, have realised an income of £10,000 a year during the last 30 years of his life when he earned almost nothing by professional services. "Taking the duration of his life into account, this son of a blacksmith and apprentice to a book-binder had to decide between a fortune of £1,50,000 on the one hand and his undowered science on the other. He chose the latter and died a poor man. But his was the glory of holding aloft among the Nations the scientific name of England for a period of 40 years." Lives of such great scientists as Faraday's are for ever a beaconlight for the succeeding generations of scientific workers.

TECHNOLOGY AND SCIENCE IN THE PLANNING CONCEPT

Technology and science have been given a pride of place in the planning concept of modern India and much of the success which has attended the efforts of those who tried to build up and develop these institutes is due to that dynamic personality and statesman who was once a sudent of science and has been, fortunately for the country, Prime Minister and the Guiding Star of India since the dawn of independence. Simultaneously with the development of the national laboratories, steps have been taken to provide greater facilities in the Universities for carrying on research, both fundamental and applied, and the generous grants recently given by the University Grants Commission — which it is hoped will be given in a larger measure in future — have been greatly appreciated by the Universities. Thus the Universities have, for the first time, been enabled to plan ahead and to organize research departments in many scientific disciplines and in other spheres of higher learning. All this however needs a much greater amount of emphasis in the educational pattern which must be adopted in conformity with the growing needs of a global concept of scientific advance. It is here perhaps that a greater amount of lee-way has yet to be made and if India were to progress and to keep abreast of the times, if it is to be independent not merely in the political field but, what is equally if not more important, in the scientific and creative fields of human endeavour, it is obvious that urgent measures have to be taken to provide for the right type of education, scientific and otherwise, to train the young men in such a way that their creative talents will be stimulated and that the opportunities for their acquiring the knowledge so plentifully available to-day are not diminished by any limited idea of parochial or provincial patriotism.

THE LANGUAGE OF SCIENCE

The language that science speaks is international and one must recognise that whatever may be the vehicle through which scientific thought can be conveyed, the use of this international language is absolutely essential if progress in science in any country is to be speeded up. And so it is that a plea is made to those who hold a different view point that under present circumstances and taking into consideration the urgent needs of the country, nothing should be done to hamper, delay or embarrass the development of scientific education whatever may be the vehicle through which such education may be possible at present: what that vehicle should be, there could be no doubt in the minds of scientists.

RESEARCH IN FUNDAMENTAL AND APPLIED SCIENCE

It is hardly necessary to emphasize the fact that research both in fundamental and applied sciences should be encouraged in every manner possible. Occasionally there is a great deal of emphasis laid upon applied research to produce quick results: and, while it is conceded that science in its larger and more comprehensive sense is to be considered in relation to what it can do for human welfare, nothing should be done to impede the progress of pure science as well. It was J. J. Thomson who said: "Research in applied science leads to reforms; research in pure science leads to revolution." This fact has been demonstrated over and over again in all the great discoveries of science. It is not always wise to emphasize the utilitarian point of view in any piece of research for, if that had been the main consideration, some of the greatest discoveries of the age which have stimulated many of the researches in applied science would never have been possible. When Archimedes ran through the streets of Syracuse shouting in Greek, "Eureka, Eureka," "I have found it, I have found it," he described the principle that every solid body lighter than a liquid in which it floats sinks so deep that the mass of liquid, which has the same volume with the submerged part, weighs just as much as the floating body. It might have meant nothing to that generation but we realise to-day that it is this principle of hydro-statics that is the basis of all problems of floatation and naval architecture.

Likewise when Professor Faraday demonstrated his famous experiment that when a magnet is brought suddenly near a coil of wire, a slight current of electricity is produced in the wire, even such a great scholar and statesman as Mr. Gladstone asked him the question : "After all, what use is it?" "Why, sir," replied Faraday, "there is every probability that you will soon be able to tax it." And to-day, no Finance Minister could afford to neglect the revenue directly and indirectly obtained through taxing this great energy, electricity.

SCIENCE FOR ITS OWN SAKE

The plea, 'science for its own sake', has been put forward clearly and forcibly by Sir Edward Appleton in his Presidential Address to the British Association for the Advancement of Science in September, 1953. "I have long held the belief," said Sir Edward, "that the cost of scientific research is the price we must pay for our industrial progress. But we should be misleading the public as well as ourselves if we based our case for the general support of the pursuit of science on its utilitarian aspects alone. I know that we can claim that many discoveries in pure science, which in their time had no obviously practical import, have later proved to be the foundation of major improvements in every material civilization. But even that is an argument of profit and loss and, to my mind, does not bring us entirely to the heart of the matter. I should like to go back beyond the achievements to the example of the scientist, be he amateur or professional — who is impelled solely by a passionate desire to explore and understand. That is what I mean by science for its own sake — when knowledge and insight are sufficient rewards in themselves." A clearer exposition of the principle 'science for its own sake' cannot be made.

SOME FAMOUS SCIENTISTS AND THEIR OCCUPATIONS

It is well also to realise that great discoveries of science may sometimes be produced in unexpected quarters and by persons who may not be necessarily in the forefront of scientific workers. Men and women of different races, walks of life, temperaments and professions have become famous scientists. Leonardo da Vinci was an artist, Sir William Herschell a band leader, Lavoisier a tax collector and Priestly a clergyman; Marie Curie was a political exile, Joule a brewer, Edison a telegraph operator, Einstein a Patent Office clerk, Faraday a bookbinder, Halley a gourmet and Newton a recluse. Many are the names of persons in diverse avocations who could be cited as great scientific discoverers of all ages. In our own country, the great genius, Ramanujam, the mathematical prodigy next perhaps only to Newton, was a clerk in the Port Trust of Madras. So lie buried amidst anonymity some of the great scientists who have made their names immortal. These men and women had in common a passionate devotion to science. It has been aptly stated that genius flashes forth like a meteor unproduced and unpredictable. It is not limited to any race of people or to any particular latitude or longitude. It has often come up from obscurity and has flourished under poverty and persecution as well as under the smiles of fortune. At present, we can only hope and pray that it will come often in our country. Fortunately genius has a way of asserting itself in every age. We may feel confident that there will be future Aristotles, Galileos, Newtons, Faradays, Pasteurs, Freuds, Ramanujams and Einsteins to provide new insight into the eternal mystery of the universe.

SCIENCE AND SOCIETY

The relations of science to society in health, in industry and in thought have been full of promise; but it is a humiliating admission that the five decades of the present century have witnessed the catastrophe of two World Wars and of many smaller conflicts. Even the period following the cessation of hostilities in 1945 has been marked by conflict or international friction in many parts of the world — Europe, Africa, and Asia. Yet during this time, scientific achievements have been so outstanding and so full of promise for the greater possibilities of human welfare than ever before.

The social need of the period requires scientific planning. The advances of biochemistry and chemotherapy have shown that on this side, science is going to be more effective in human affairs than it has ever been in the past. The whole world can be changed more quickly now by some chemical discovery such as that of Paludrin for malaria. And to-day the World Health Organization, taking note of these significant advances, has launched boldly and wisely on a programme of eradication of diseases rather than of control of diseases. The eradication of malaria is no longer a theoretical problem for it has been effectively proved that by modern methods of scientific investigation and application it could be accomplished. This naturally necessitates scientific planning so that individual scientists, often working in ignorance of the wider implication of their efforts to develop this or that field, may be guided to the more urgent needs of society so that the time lag may be saved with the saving of millions of human lives. The implication is not so much that scientists should be directed to this or that particular purpose but rather that a better system of scientific education should be adopted to a society consciously aimed at securing the maximum human welfare.

TRADITION AND SCIENCE

But the application of scientific remedies is not altogether easy in an atmosphere where ignorance and prejudice prevail. In science as in politics, a break with tradition has always meant a liberation of human inquiry into hitherto closed fields. If science does not progress as rapidly as it ought to and its beneficent influences do not reach the masses of the people, it is more often than not due to ancient customs and beliefs and to a certain extent, very naturally, to hesitation to discard such beliefs. The greatest difficulty of discovery is not so much to make the necessary observation but to break away from traditional ideas in interpreting them. From the time when Copernicus established the movement of the earth and Harvey the circulation of blood down to when Einstein abolished the ether, the real struggle has been less to penetrate the secrets of nature than to overthrow established ideas even though in their time they might have helped in some way the advancement of human knowledge.

War however produced the most outstanding example of the conscious use of science in the 20th century: industry, agriculture, medicine: and even science itself began to be planned instead of being left to the chance of economic forces. This growing consciousness of the function of science was one of the most characteristic features of the 20th century social relations. Science became fully, consciously and immediately what it had long been unconsciously considered, an essential part of production. It was something worth investing in, directly by setting up of research laboratories connected with various industries or indirectly by subsidising Universities where the workers for these laboratories could be trained and where basic research could be carried out. The number of research laboratories established in various large scale industries and the many research projects which Universities are being asked to undertake in connection with industrial advances are proof positive, if such proof were indeed necessary, that science can pay its way if it is properly utilised.

SCIENCE KNOWS NO FRONTIERS

Science knows no frontiers. Perhaps the best example of this is the observance of the International Geophysical Year which is noteworthy not only because of its intrinsic value and the popular interest evinced throughout the world in this venture but also because it is a supreme example of scientific co-operation among all nations when, in other fields unfortunately, ideologies of a conflicting nature are so clearly manifest. It is becoming more and more appreciated that no discovery of science can be hidden for long. At the international conference on the Peaceful Uses of Atomic Energy held at Geneva in August 1955, the President of the Conference, our esteemed friend, Dr. Bhabha, said: "Knowledge once given cannot be taken back." A significant statement coming from an outstanding scientist of the day. In the light of this fact, the feverish heat with which nations are trying to compete with each other in the race for some scientific discovery not necessarily of a nature that will be productive of good but unfortunately of a type that is more designed to destroy than to create or preserve seems indeed a tragedy too deep for words to describe.

SCIENCE FOR THE WELFARE OF HUMANITY

In another sense, all the secrecy and the mystery that surrounds some of our scientific works would, on a correct appreciation of the position, seem to be love's labour lost. The scientist to-day is unfortunately between two compelling forces, one trying to utilise the basis of the discoveries for the good of humanity and the other equally concerned and equally eager to utilise the great discoveries of science to uses which can only lead to the destruction of humanity with consequences too staggering even for the imagination to dwell upon. It was a realisation of this factor that led to scientists protesting, in season and out of season, against the abuse of scientific discoveries for destructive purposes. The biological warfare, that was once threatened, led to a protest from scientists and, at the International Congress of Micro-biologists held in Rome in 1953, the following resolution was passed. "The Sixth International Congress for Microbiology, confident of interpreting the thought of all microbiologists, expresses its view that the science of microbiology should have as its sole aim the welfare and progress of humanity: that all microbiological research should be directed to this end; and that all countries should adhere to the 1925 Geneva Protocol." May we not hope that in the sphere of atomic science as well, a similar declaration would be made: that all atomic energy would be used only for peaceful purposes and that every discovery would be turned to endeavours for the improvement of conditions of living of human society: that the psychological warfare, which has unfortunately been continued for too long a period, would end and that the Commissions now in conference to concentrate upon how best to lesson international tensions would be given divine guidance such that humanity may be spared the horrors of world conflicts and the consequent deprivation of precious lives and the degradation of human society.

THE GREAT UNKNOWN

Spectacular as these great discoveries have been, yet every day witnesses a new epoch-making event which stuns the imagination of millions of people. It would almost appear as if this is just the beginning of a new era of unimaginable discoveries. As we scan the skies and behold the great doors of the secrets of nature unfolding, we are struck dumb with amazement and with humility. In Jean Paul Richter's beautiful dream, a man was called up into the vestibule of heaven and carried to universe upon universe in endless space, until his mind reeled before the transcendental distances which were still before him. Then the man sighed and stopped, shuddered and wept. His overladen heart uttered itself in tears and he said: "Angel, I will go no further: for the spirit of man acheth with this infinity. Insufferable is the Glory of God. Let me lie down in the grave and hide me from the persecution of the Infinite, for end I see there is none." Then the Angel lifted up his glorious hands to the heaven of heavens, saying "End is there none to the universe of God. Lo! also is there no beginning."

SECTION OF MATHEMATICS

PRESIDENT : DR. M. RAY, D,Sc., F.N.I.

Presidential Address

REAL FLUID FLOW

1. INTRODUCTION

Ideal fluid is inviscid and incompressible. In the flow of such a fluid there is no tangential force between adjoining layers of fluid but only the normal force, that is, the pressure. The theory of ideal fluid gives satisfactory explanation for some phenomena of the flow such as wave motion, the lift of an aerofoil, etc., but fails to explain many other phenomena such as skin friction, no slippage on the surface of a solid body, etc. Actual fluids are in general viscous and compressible. Viscosity is the characteristic of actual fluids which exhibits a certain resistance to alterations of form. In such a fluid motion, both the tangential and the normal forces exist.

The density of some fluids, particularly gases, changes considerably with the speed of the flow and the temperature of the fluids. In fact compressions and expansions of the fluid are accompanied by change in temperature. Whenever there is a temperature gradient in the field of flow, there is flow of heat through conduction and convection. *Real fluid is thus viscous, compressible and heat-conducting.*

Fluids are considered as continuous media and the condition at any point is determined by the physically measurable quantities, density, pressure and temperature, between which usually a functional relation exists. Besides these three, there are the three components of velocity, thus there are six unknowns, namely, the pressure p, the density ρ, the temperature T and the three components of velocity (u, v, w), which are functions of spatial coordinates (x, y, z) and time t. We should use six relations to determine these six unknowns. These relations are the equation of continuity, that is, the conservation of mass of the fluid, the equations of motion (three in number), that is, the conservation of momentum of the fluid, the equation of energy, that is, the conservation of energy of fluid and the equation of state of the fluid, that is, the functional relation between p, ρ and T. The fundamental equations of motion which are known as Navier-Stokes equations are non-linear and very little is known about the mathematical properties of these equations. Further these equations involve the coefficients of viscosity and heat conduction which are in general functions of velocity and thus the equations become highly non-linear. There is no general method for the solution of these equations, only for a small number of cases when we make some assumptions about the state of the fluid and consider very simple configuration for the flow pattern, we can find the exact solutions of the equations. The only possible exact solution for the flow of a viscous compressible fluid is steady flow with one spatial coordinate. The equations may however be simplified by considering the limiting cases of very large viscosity or of vanishingly small viscosity. Even in these limiting cases the mathematical methods are very difficult and inconvenient. That is why most attempts to obtain information on the behaviour of real fluids are experimental investigations. Model tests are usually conducted under a set of conditions different from the actual case. In order to correlate the various tests with each other as well as with theory, we take recourse to the laws of similarity without actually solving the differential equations. If L be the characteristic length, U the representative velocity in the flow, ρ the density and μ the coefficient of viscosity, then forms of flows of fluid around geometrically similar boundaries will themselves be geometrically similar if Reynolds number $R_e = \frac{\rho UL}{\mu}$, Mach number $M = \frac{U}{a}$ (a = local velocity of sound), $\gamma = \frac{C_p}{C_v}$ (C_p = specific heat at constant pressure, C_v = specific heat at constant volume) and Prandtl number $\sigma = \frac{\mu C_p}{k}$ (K = coefficient of heat conduction) are the same. Reynolds number also represents the ratio of inertial force to viscous force. Hence when Reynolds number is small, the viscous force is predominant and when it is large, the inertial force is predominant and the effect of viscosity is important only in a narrow region near the solid boundary. If the Reynolds number is enormously large, the flow becomes turbulent. Similarly Prandtl number gives the relative importance of the heat conduction and viscosity of the fluid. For real fluids, particularly gases, the Prandtl number is of the order of unity so that whenever we take into account the effect of viscosity, we must simultaneously take into account the influence of thermal conductivity. These two numbers, Reynolds number and Prandtl number, play very important parts in the theory of real fluids.

2. FUNDAMENTAL EQUATIONS

Fluid may be regarded as a continuous elastic medium with this difference that in a purely elastic body the strain represents the deformation of the shape of the body whereas in a fluid, the strain refers to the deformation of the velocity. In such a medium a system of stress and strain is set up and the simplest physical law connecting the stress and the strain is that the stress-components are linear functions of the rate-of-strain components and that in an isotropic medium their properties are the same in all directions, that is, the relations between the stress-components and the rate-of-strain components must be independent of the choice of axes. These are in fact tensors of rank two.

Equations of motion can be conveniently obtained from the theory of Elasticity$^{(1)}$. If α, β and γ be functions of x, y, z, let the surfaces $\alpha = \text{const.}$, $\beta = \text{const.}$, $\gamma = \text{const.}$ form an orthogonal system then the element of length is given by

$$ds^2 = \left(\frac{d\alpha}{h_1}\right)^2 + \left(\frac{d\beta}{h_2}\right)^2 + \left(\frac{d\gamma}{h_3}\right)^2 \qquad \ldots \quad (1)$$

where

$$\frac{1}{h_1^2} = \left(\frac{\partial x}{\partial \alpha}\right)^2 + \left(\frac{\partial y}{\partial \alpha}\right)^2 + \left(\frac{\partial z}{\partial \alpha}\right)^2 \qquad \ldots \quad (2)$$

and similarly for h_2 and h_3.

If u, v, w be the components of velocity in the directions of α, β, γ, the components of rate-of-strain are

$$e_{\alpha\alpha} = h_1 \frac{\partial u}{\partial \alpha} + h_1 h_2 v \frac{\partial}{\partial \beta}\left(\frac{1}{h_1}\right) + h_1 h_3 w \frac{\partial}{\partial \gamma}\left(\frac{1}{h_1}\right) \qquad \ldots \quad (3)$$

and similarly for $e_{\beta\beta}$, $e_{\gamma\gamma}$,

$$e_{\beta\gamma} = \frac{h_3}{h_2}\frac{\partial}{\partial \gamma}(h_2 v) + \frac{h_2}{h_3}\frac{\partial}{\partial \beta}(h_3 w) = e_{\gamma\beta}, \qquad \ldots \quad (4)$$

and similarly for $e_{\gamma\alpha}$, $e_{\alpha\beta}$.

The dilatation which is the measure of expansion, is

$$\Delta = e_{\alpha\alpha} + e_{\beta\beta} + e_{\gamma\gamma}. \qquad \ldots \quad (5)$$

The stress components are

$$\left.\begin{array}{l} p_{\alpha\alpha} = -p + \lambda\Delta + 2\mu e_{\alpha\alpha},\ p_{\beta\beta} = -p + \lambda\Delta + 2\mu e_{\beta\beta},\ p_{\gamma\gamma} = -p + \lambda\Delta + 2\mu e_{\gamma\gamma} \\ p_{\beta\gamma} = \mu e_{\beta\gamma} = p_{\gamma\beta},\ p_{\gamma\alpha} = \mu e_{\gamma\alpha} = p_{\alpha\gamma},\ p_{\alpha\beta} = \mu e_{\alpha\beta} = p_{\beta\alpha}, \end{array}\right\} (6)$$

where λ, μ are the two coefficients of viscosity.

The equations of motion are

$$\left.\begin{aligned} & h_1h_2h_3\left[\frac{\partial}{\partial\alpha}\left(\frac{p_{\alpha\alpha}}{h_2h_3}\right)+\frac{\partial}{\partial\beta}\left(\frac{p_{\alpha\beta}}{h_3h_1}\right)+\frac{\partial}{\partial\gamma}\left(\frac{p_{\gamma\alpha}}{h_1h_2}\right)+\frac{p_{\alpha\beta}}{h_3}\frac{\partial}{\partial\beta}\left(\frac{1}{h_1}\right)\right. \\ & \left.+\frac{p_{\gamma\alpha}}{h_2}\frac{\partial}{\partial\gamma}\left(\frac{1}{h_1}\right)-\frac{p_{\beta\beta}}{h_3}\frac{\partial}{\partial\alpha}\left(\frac{1}{h_2}\right)-\frac{p_{\gamma\gamma}}{h_2}\frac{\partial}{\partial\alpha}\left(\frac{1}{h_3}\right)\right]+\rho F_\alpha=\rho f_\alpha \end{aligned}\right\} \quad (7)$$

and similar two equations,

where $(F_\alpha, \ldots)$ are the components of body forces per unit mass and $(f_\alpha \ldots)$ components of acceleration in the directions of α, β, γ respectively.

The equations of motion in cartesian, cylindrical and spherical coordinates can be easily obtained from the above equations.

The equation of continuity is obtained from the law of conservation of mass which states that the increase in the mass of fluid within a closed surface drawn in it in any time interval is equal to the excess of the mass that flows in over the mass that flows out and is given by

$$\frac{D\rho}{Dt}+\rho\Delta=0 \qquad \ldots \quad (8)$$

where the operator D/Dt has the usual hydrodynamical significance.

The equation of energy is obtained from the law of conservation of energy which states that the difference in the rate of supply of energy to any volume fixed in space and the rate at which energy goes out through its surface must be the net rate of increase of energy inside the volume. If T be the absolute temperature, E the internal energy per unit mass, the equation of energy comes out as⁽²⁾,

$$\rho\left\{\frac{DE}{Dt}+p\frac{D}{Dt}\left(\frac{1}{\rho}\right)\right\}=\frac{\partial}{\partial x_\alpha}\left(k\frac{\partial T}{\partial x_\alpha}\right)+\Phi \qquad \ldots \quad (9)$$

(summation convention—being used)

where Φ, known as the dissipation function, is given by

$$\Phi=\lambda\Delta^2+\mu[2(e^2_{\alpha\alpha}+e^2_{\beta\beta}+e^2_{\gamma\gamma})+e^2_{\beta\gamma}+e^2_{\gamma\alpha}+e^2_{\alpha\beta}]. \qquad \ldots \quad (10)$$

The equation of state is the functional relation between p, ρ, T. For a perfect gas the relation is approximately taken as

$$p=R\rho T \qquad \ldots \quad (11)$$

where R is the gas constant given by

$$R=C_p-C_v. \qquad \ldots \quad (12)$$

We will take the above equation as the equation of state of a real fluid.

Taking $$i = C_p T \qquad \dots (13)$$

which will be called the enthalpy, we get

$$i\rho = C_p\, \rho T = \frac{C_p}{R}\, p = \frac{C_p}{C_p - C_v}\, p = \frac{\gamma}{\gamma - 1}\, p. \qquad \dots (14)$$

In terms of i, the equation of energy takes the form

$$\rho \frac{Di}{Dt} = \frac{Dp}{Dt} + \frac{\partial}{\partial x_a}\left(\frac{\mu}{\sigma} \cdot \frac{\partial i}{\partial x_a} \right) + \Phi, \qquad \dots (15)$$

if C_p is constant.

The two coefficients of viscosity λ, μ are not in general independent. For monatomic gas, there is the Stoke's assumption

$$3\lambda + 2\mu = 0. \qquad \dots (16)$$

This ensures spherical symmetry such that the pressure p is the average normal stress in the fluid. Thus there is in general only one coefficient of viscosity, namely, μ but the second coefficient λ plays a very important role in many cases, particularly when the flow velocity reaches ande xceeds the sound velocity (3). We will however take the equation (16) to be generally true.

3. SOME EXACT SOLUTIONS

Exact solutions of very few problems could be found because of the high non-linearity of the differential equations. The simplest case is the solution for one-dimensional steady flow with zero body forces. In this case the equations are

$$\left.\begin{aligned} &\rho u \frac{du}{dx} + \frac{dp}{dx} - \frac{4}{3}\frac{d}{dx}\left(\mu \frac{du}{dx}\right) = 0 \\ &\frac{d}{dx}(\rho u) = 0 \\ &\rho C_v u \frac{dT}{dx} + p\frac{du}{dx} - \frac{4}{3}\mu\left(\frac{du}{dx}\right)^2 - \frac{d}{dx}\left(K\frac{dT}{dx}\right) = 0 \end{aligned}\right\} \qquad \dots (17)$$

and $$p = R\rho T.$$

An exact solution can be found when $\sigma = \frac{3}{4}$, which is very nearly true for air and if the flow is uniform at plus infinity, we get the well-known energy equation, namely,

$$i + \frac{1}{2} u^2 = \text{constant}. \qquad \dots (18)$$

Illingworth(4) showed that the only solution which can be found in closed form is that of uniform shearing motion in the Couette flow between parallel flat plates in relative motion.

Taking one of the plates as $y = 0$, all quantities are functions of y only and the equations become

$$\left.\begin{aligned} &\frac{d}{dy}(\rho\, v) = 0 \\ &\frac{d}{dy}\left(\mu \frac{du}{dy}\right) = 0 \\ &\frac{dp}{dy} + g\rho = 0 \\ \text{and} \quad &\frac{d}{dy}\left(\mu \frac{di}{dy}\right) + \mu\sigma\left(\frac{du}{dy}\right) = 0 \end{aligned}\right| \quad \ldots \quad (19)$$

where the only body force is the gravitational force perpendicular to the plates.

Solution is of the form

$$\left.\begin{aligned} &i + \tfrac{1}{2}\sigma u^2 - au = \text{constant} \\ \text{and} \quad &\int \mu du - by = \text{constant} \end{aligned}\right\} \quad \ldots \quad (20)$$

where a, b are constant.

With μ given in terms of i, usually proportional to it, the solution is complete.

Illingworth also showed that solution for the steady Poiseuille flow through a circular pipe can not be found in a closed form in the general case. Ray(5) found the solution of the Poiseuille flow when μ is constant and σ is unity. Taking the z-axis along the axis of the pipe and using cylindrical coordinates (r, θ, z) so that all quantities are independent of θ, the equations reduce to the following

$$0 = -\frac{\partial p}{\partial r} + \frac{1}{3}\mu \frac{\partial^2 w}{\partial r \partial z}$$

$$\rho w \frac{\partial w}{\partial z} = -\frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial r^2} + \frac{1}{r}\frac{\partial w}{\partial r} + \frac{4}{3}\frac{\partial^2 w}{\partial z^2}\right.$$

$$\frac{\partial}{\partial z}(\rho w) = 0 \quad \ldots \quad (21)$$

$$\rho w \frac{\partial i}{\partial z} = w\frac{\partial p}{\partial z} + \frac{\mu}{r}\frac{\partial}{\partial r}\left(r \frac{\partial i}{\partial r}\right) + \mu\frac{\partial_2}{\partial z^2} + \frac{4}{3}\mu\left(\frac{\partial w}{\partial z}\right) + \mu\left(\frac{\partial w}{\partial r}\right)^2$$

and $$i\rho = \frac{\gamma}{\gamma - 1}p.$$

Solutions are found in the following forms

$$\left.\begin{aligned} w &= w_0 e^{-\alpha z} J_0(Kr) \\ p &= p_0 + \frac{1}{3} \alpha\mu w_0 \{1 - e^{-\alpha z} J_0(Kr)\} \\ i &= i_1 + i_0 e^{-\alpha z} J_0(Kr) - i_1 e^{-2\alpha z} + \frac{1}{64} e^{-2\alpha z} K^4 r^4 w_0^2 \left(1 + \frac{1}{9} K^2 r^2 + -\right) \\ &\quad + \ldots\ldots \end{aligned}\right\} \quad (22)$$

where the suffix zero indicates value at the centre of the mouth of the pipe, i_1 corresponds to hydrostatic temperature and the constants are given by the relations

$$K^2 = \alpha^2 + \frac{\alpha}{\mu} \rho_0 w_0, \quad J_0(Ka) = 0, \qquad \ldots \quad (23)$$

a being the radius of the pipe.

The problems of the steady source-flow or sink-flow in two dimensions have been studied by Lovey(6) and Yao-Tsu Wu(7) respectively. Though exact solutions could not be found for all values of μ and σ, sufficient insight has been given into the nature of the flow. For inviscid fluid there is an exact solution which has a limit line called the sonic circle where the fluid velocity equals the local speed of sound. To the exterior of this sonic circle the solution has two branches of values, one representing a supersonic speed and the other a subsonic speed, such that both these branches terminate at the sonic circle with infinite velocity gradient. It is therefore expected that the viscous and heat conducting effects will play an important part in continuing the solution into the inside of the sonic circle. Starting with this solution as a guide, the differential equations can be simplified for a particular value of σ and with μ = const. Though the method is very much involved, several important features have been found by studying the nature of the solution curves. For any value of σ but with μ = const., PLK (Poincare-Lighthill-Kuo) method has been successfully applied. The PLK method is a modified perturbation process where not only the dependent variables, for instance, the velocity component but also the independent variables, for instance, the coordinates, are expanded in power series of a small parameter occurring in the differential equation. In ordinary perturbation method if the zeroth order solution has a singularity, that singularity becomes all the more worse in higher order solutions but in PLK method sufficient ingenuity can be devised to remove this singularity and in many cases uniform and convergent solutions can be found. Though considerable success has been achieved in solving the two-dimensional problem, the problem in three dimensions is rather formidable and is still untractable.

Problem of the velocity distribution with suction on a flat plate of infinite extent in incompressible flow due to Grifith and Meredith can be extended to the case of unsteady flow of real fluid in the following manner without any approximation but under some simplifying assumptions. These assumptions are (1) p constant, (2) σ unity, (3) C_p constant, (4) μ proportional to T.

Measuring y perpendicularly to the plate, all quantities are functions of y only, so that the equations are

$$\rho\left(\frac{\partial u}{\partial t} \quad v\frac{\partial u}{\partial y}\right)=\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right)$$

$$\rho\left(\frac{\partial v}{\partial t}+v\frac{\partial v}{\partial y}\right)=\frac{4}{3}\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right)$$

$$\frac{\partial\rho}{\partial t}+\frac{\partial}{\partial y}(\rho v)=0 \qquad (24)$$

$$\rho\left(\frac{\partial i}{\partial t}+v\frac{\partial i}{\partial y}\right)=\frac{\partial}{\partial y}\left(\mu\frac{\partial i}{\partial y}\right)+\mu\left\{\frac{4}{3}\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial u}{\partial y}\right)^2\right\}$$

and $\quad i\rho = \text{constant} = i_1\rho_1$

where the suffix unity denotes values at $y=\infty$.

Also from the fourth assumption $\frac{\mu}{i}=$ const.

so that $\mu\rho = \text{constant} = \mu_1\rho_1$. ... (25)

Boundary conditions are

$$\left.\begin{array}{llll}\text{(a)} & \text{at } y=0, & u=0=v, & i=i_0\\ \text{(b)} & \text{at } y=\infty, & u=u_1,\ v=v_1, & i=i_1\end{array}\right\} \quad \ldots \quad (26)$$

where, for suction, v_1 is negative.

The equation of continuity can be satisfied by

$$\rho=\frac{\partial\psi}{\partial y},\quad \rho v=-\frac{\partial\psi}{\partial t}. \quad \ldots \quad (27)$$

Changing the independent variables (t, y) to (t, ψ) by means of the formulae

$$\left(\frac{\partial}{\partial y}\right)_t=\rho\left(\frac{\partial}{\partial\psi}\right)_t,\ \left(\frac{\partial}{\partial t}\right)_y=\left(\frac{\partial}{\partial t}\right)_\psi-\rho v\left(\frac{\partial}{\partial\psi}\right)_t,$$

the other equations reduce to

$$\frac{\partial u}{\partial t}=\mu_1\rho_1\frac{\partial^2 u}{\partial\psi^2}$$

$$\frac{\partial v}{\partial t}=\tfrac{4}{3}\mu_1\rho_1\frac{\partial^2 v}{\partial\psi^2} \quad \ldots \quad (28)$$

and $$\frac{\partial i}{\partial t}=\mu_1\rho_1\frac{\partial^2 i}{\partial\psi^2}+\mu_1\rho_1\left\{\tfrac{4}{3}\left(\frac{\partial v}{\partial\psi}\right)^2+\left(\frac{\partial u}{\partial\psi}\right)^2\right\}$$

Taking $\eta = \dfrac{\psi}{2(\mu_1\rho_1 t)^{\frac{1}{2}}}$, we easily find

$$u = u_1\, erf(\eta) \qquad \ldots \quad (29)$$

if $\eta = \infty$ corresponds to $y = \infty$.

Further $$d\psi = \left(\frac{\partial\psi}{\partial t}\right)_\eta dt + \left(\frac{\partial\psi}{\partial\eta}\right)_t d\eta$$

$$= \left(\frac{\partial\psi}{\partial y}\right)_t dy + \left(\frac{\partial\psi}{dt}\right)_y dt$$

gives with $\psi = 2\eta(\mu_1\rho_1 t)^{\frac{1}{2}}$

$$\eta\left(\frac{\mu_1\rho_1}{t}\right)^{\frac{1}{2}} dt + 2(\mu_1\rho_1 t)^{\frac{1}{2}}\, d\eta = \rho dy - \rho v dt$$

so that $$\rho v = -\eta\left(\frac{\mu_1\rho_1}{t}\right)^{\frac{1}{2}} \qquad \ldots \quad (30)$$

and $$\rho dy = 2(\mu_1\rho_1 t)^{\frac{1}{2}} d\eta \qquad \ldots \quad (31)$$

thus $\eta = 0$ corresponds to $y = 0$.

Then we find $$v = \frac{2v_1}{\sqrt{3}}\, erf\left(\frac{2}{\sqrt{3}}\eta\right) \qquad \ldots \quad (32)$$

and $$i = i_0 + C\, erf(\eta) - \frac{u_1^2}{2}\{erf(\eta)\}^2 - \frac{16}{3\pi} v_1^2 f, \qquad \ldots \quad (33)$$

where $f = \int_0^\eta e^{-\eta^2}\left(\int_0^\eta e^{-\frac{1}{2}\eta^2}\, d\eta\right)d\eta$, and C a constant.

To complete the solution, we find the transformation equation connecting y with η.

We have $$\frac{dy}{d\eta} = \frac{2}{\rho}(\mu_1\rho_1 t)^{\frac{1}{2}} = \frac{2i}{i_1}\left(\frac{\mu_1 t}{\rho_1}\right)^{\frac{1}{2}}$$

hence $$y = \frac{2}{i_1}\left(\frac{\mu_1 t}{\rho_1}\right)^{\frac{1}{2}}\left[\, i_0\eta + C\left\{\eta\, erf(\eta) + \frac{1}{\sqrt{\pi}} e^{-\eta^2}\right\}\right.$$

$$\left. - \frac{u_1^2}{\sqrt{\pi}}\left\{\sqrt{\frac{\pi}{2}}\eta\, erf^2(\eta) + e^{-\eta^2} erf(\eta) - \frac{1}{\sqrt{2}} erf(\eta\sqrt{2})\right\} - \frac{16v_1^2}{3\pi} F\,\right] \qquad \ldots \quad (33)$$

where $$F = \int_0^\eta f d\eta. \qquad \ldots \quad (34)$$

The values of f and F can be found by numerical quadrature. It is found that when $\eta \to \infty$, $f \to .44$ nearly hence the value of the constant C can be obtained from the condition $\eta \to \infty$, $i \to i_1$. Further it is seen that when $\eta \to \infty$, $F \to \infty$ as well, hence y also $\to \infty$. This completes the solution.

4. THE BOUNDARY LAYER EQUATIONS :

In the limiting case of vanishingly small viscosity or very large Reynolds number, the effect of viscosity is confined to a very thin layer near the boundary. This means that when-ever a fluid of small viscosity flows past a solid surface, the transition from the velocity of the surface to that of the main stream is accomplished in a narrow layer near the surface. This narrow layer is called the Boundary Layer according to Prandtl. In the case of real fluids, there is not only a velocity boundary layer but also a temperature boundary layer in which the temperature changes rapidly from that of the boundary of the surface to that of the free stream. These layers may be visualized as regions in which the rates of change in the direction parallel to the surface. of the velocity components and their derivatives as well as of the temperature and its derivatives are all small and may be neglected compared with the corresponding rates of change normal to the surface. With these approximations Prandtl obtained the following equations in two dimensions true inside the boundary layer, x being measured along the plane;

$$\left.\begin{aligned} \rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) &= -\frac{\partial p}{\partial x} + \frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right) \\ 0 &= -\frac{\partial p}{\partial y} \\ \text{and} \qquad \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) &= 0. \end{aligned}\right\} \quad \ldots \quad (35)$$

If σ is of the order of unity, which means that the thickness of the temperature boundary layer is of the same order of magnitude as that of the velocity boundary layer, the equation of energy becomes

$$\rho\left(\frac{\partial i}{\partial t} + u\frac{\partial i}{\partial x} + v\frac{\partial i}{\partial y}\right) = \frac{\partial p}{\partial t} + u\frac{\partial p}{\partial x} + \frac{\partial}{\partial y}\left(\frac{\mu}{\sigma}\frac{\partial i}{\partial y}\right) + \mu\left(\frac{\partial u}{\partial y}\right)^2. \quad \ldots \quad (36)$$

These equations are still non-linear though much simpler than the original Navier-Stokes equations.

5. SOME TYPICAL PROBLEMS

The most important problem that has attracted very wide attention is the boundary layer on a flat plate. For steady flow, if we multiply the first equation in (35) by u and add to (36) we have

$$\rho u \frac{\partial}{\partial x}(i+\tfrac{1}{2}u^2)+\rho v\frac{\partial}{\partial y}(i+\tfrac{1}{2}u^2) = \frac{\partial}{\partial y}\left\{\mu \frac{\partial}{\partial y}(i+\tfrac{1}{2}u^2)\right\} + \left(\frac{1}{\sigma}-1\right)\frac{\partial}{\partial y}\left(\mu\frac{\partial i}{\partial y}\right) \quad \ldots \quad (37)$$

If $\sigma = 1$, we see that $$i+\tfrac{1}{2}u^2 = \text{const.} \quad \ldots \quad (38)$$

is a particular integral, no matter what the pressure distribution.

If $\dfrac{dp}{dx} = 0$ and $\sigma = 1$ then the solution is easily found to be

$$i+\tfrac{1}{2}u^2 = au+b \quad \ldots \quad (39)$$

where a and b are constants.

This was first discovered by Crocco(8).

To solve the equation for any value of σ, Crocco used x and u as independent variables instead of x and y so that the transformation formulae are

$$\frac{\partial}{\partial x} = \frac{\partial}{\partial x} - \frac{\dfrac{\partial y}{\partial x}}{\dfrac{\partial y}{\partial u}}\cdot\frac{\partial}{\partial u}, \quad \frac{\partial}{\partial y} = \frac{1}{\dfrac{\partial y}{\partial u}}\,\frac{\partial}{\partial u}$$

and this is possible only when the corresponding Jacobian does not vanish, that is, $\partial y/\partial u$ is not zero and then the equations reduce to, in terms of the shearing stress

$$\tau = \frac{\mu}{\dfrac{\partial y}{\partial u}},$$

$$\left.\begin{aligned} & u\frac{\partial}{\partial x}\left(\frac{\rho\mu}{\tau}\right) + \frac{\partial^2\tau}{\partial u^2} = 0 \\ \text{and} \quad & (1-\sigma)\frac{\partial i}{\partial u}\frac{\partial \tau}{\partial u} + \left(\frac{\partial^2 i}{\partial u^2}+\sigma\right)\tau = 0, \end{aligned}\right\} \quad \ldots \quad (40)$$

taking i as a function of u only.

Also ρ and μ are functions of i hence of u only.

Taking $\tau = \dfrac{F_1(u)}{\sqrt{2x}}$, the equations become

$$F_1F_1'' + \rho\mu u = 0 \quad \ldots \quad (41)$$

and
$$(1-\sigma)\frac{\partial i}{\partial u}F_1' + \left(\frac{\partial^2 i}{\partial u^2}+\sigma\right)F_1 = 0 \qquad \ldots \quad (42)$$

If $\sigma = 1$, the equation (42) gives at once the original Crocco's[8] relation, namely, i as a quadratic in u.

The case when $\rho\mu =$ const. can be easily solved.

Introducing the non-dimensional quantities

$$u_0 = \frac{u}{u_1},\ i_0 = \frac{i}{i_1},\ \rho_0 = \frac{\rho}{\rho_1},\ \mu_0 = \frac{\mu}{\mu_1}$$

so that $\rho\mu = \rho_1\mu_1$ gives $\rho_0\mu_0 = 1$

and putting $F_2(u_0) = \left(\dfrac{2}{\rho_1\mu_1 u_1{}^3}\right)^{\frac{1}{2}}F_1(u)$

the equation (41) becomes

$$F_2F_2'' + 2u_0 = 0. \qquad \ldots \quad (43)$$

Taking
$$u_0 = \tfrac{1}{2}\,\frac{df}{d\eta},\quad F_2 = \tfrac{1}{2}\,\frac{d^2f}{d\eta^2}$$

the above equation becomes

$$f'''+ff'' = 0. \qquad \ldots \quad (44)$$

This is the well known Blasius equation for incompressible fluid. Thus the problem reduces to the corresponding problem of the incompressible fluid. In cases when σ is different from unity, the enthalpy equation can be solved either by approximation method or by numerical integration.

There is another method of solving the problem which is as famous as the Crocco's method. That is due to Von Karman and Tsien(9). They simplified the equations with the help of Mises's transformation and took σ as unity.

With
$$\rho u = \frac{\partial\psi}{\partial y},\quad \rho v = -\frac{\partial\psi}{\partial x}$$

and using Mises's transformation, the equations reduce to

$$u\frac{\partial u}{\partial x} = u\frac{\partial}{\partial\psi}\left(\mu\rho u\frac{\partial u}{\partial\psi}\right) \qquad \ldots \quad (45)$$

and
$$\frac{\partial i}{\partial x} = \frac{\partial}{\partial\psi}\left(\mu\rho u\frac{\partial i}{\partial\psi}\right) + \mu\rho u\left(\frac{\partial u}{\partial\psi}\right)^2 \qquad \ldots \quad (46)$$

Since from Crocco's relation i is a quadratic in u, the problem reduces to solving the equation (45) only. Introducing the non-dimensional quantities u_0: ρ_0, i_0, μ_0 as before and

$$x_0 = \frac{x}{l}, \ \psi_0 = \frac{\psi}{\sqrt{\mu_1\rho_1 u_1 l}}$$

where l is a characteristic length, the equation (45) becomes

$$\frac{\partial u_0}{\partial x_0} = \frac{\partial}{\partial \psi_0}\left(\rho_0\mu_0 u_0 \frac{\partial u_0}{\partial \psi_0}\right). \qquad \ldots \quad (47)$$

Further with $\zeta = \frac{\psi_0}{\sqrt{x_0}}$, the equation (47) becomes

$$-\frac{\zeta}{2}\frac{du_0}{d\zeta} = \frac{d}{d\zeta}\left(\rho_0\mu_0 u_0 \frac{du_0}{d\zeta}\right). \qquad \ldots \quad (48)$$

To solve this equation, Von Karman and Tsien used the method of successive approximation starting with some approximate solution.
When $i_0 = \mu_0$, the equation (47) simplifies to

$$\frac{\partial u_0}{\partial x_0} = \frac{\partial}{\partial \psi_0}\left(u_0 \frac{\partial u_0}{\partial \psi_0}\right). \qquad \ldots \quad (49)$$

Putting $u_0 = \frac{1}{2}\frac{df}{d\eta}$ and $f(\eta) = \frac{\psi_0}{\sqrt{x_0}}$, the above equation becomes

$$f''' + ff'' = 0 \qquad \ldots \quad (50)$$

which is the Blasius equation.

Thus in both the methods the ultimate equation is the Blasius equation. In many problems on real fluid flow, attempt has been made to reduce the case to that for an incompressible flow by suitable transformation. This has been done by Howarth $^{(10)}$ and Stewartson$^{(11)}$ in the case when the pressure gradient is not zero. They found that when μ varies as T, it is possible to transform the coordinates so that the boundary layer equations arising from a given main stream of a compressible fluid become identical with those arising from a different main stream of the incompressible fluid. In this way the flow pattern occurring in the theory of incompressible fluid may be taken over into the theory of compressible fluid.

The general problem of the boundary layer on a cylinder is one of formidable complexity. A complete study for the case of real fluid is probably outside the scope of anyone without the aid of computing machines.

A simple exact solution of the boundary layer equations for any value of σ was given by Young(12) for the Grifith and Meredith problem mentioned earlier. He got the interesting result

$$i_1 - i = \frac{\sigma u_1^2}{2(2-\sigma)}\left\{\left(1-\frac{u}{u_1}\right)^2 - \frac{2}{\sigma}\left(1-\frac{u}{u_1}\right)\right\}. \qquad \ldots \quad (51)$$

When the fluid is slightly compressible such that the variations of density and temperature from their values in the main stream are small, Ray(13) found a solution for any value of σ, in the case when p is not constant. He found the thickness of the boundary layer in the form

$$y = \gamma\left(\frac{\mu_1 l x}{u_1\rho_1}\right)^{\frac{1}{2}}\int_0^1 \frac{df}{(e^{1-f^2}+\gamma-1)ff'} \qquad \ldots \quad (52)$$

$$\text{where}(ff')^{1-\sigma} f^{\frac{\sigma(\gamma-1)}{e}+1} = \alpha^{1-\sigma}\exp.\left[(f^2-1)-\frac{\sigma(\gamma-1)}{2e}(f^2+\tfrac{1}{4}f^4+\ldots-1.32)\right] \qquad \ldots \quad (53)$$

and on the edge

$$\frac{\partial u}{\partial y} = \left(\frac{\rho_1 u_1^3}{\mu_1 x}\right)^{\frac{1}{2}}\alpha. \qquad \ldots \quad (54)$$

The above equations have been solved by numerical quadrature. Thus the boundary layer has a parabolic shape. Only limitation is that the flow does not pass smoothly from inside the boundary layer to outside but practically does so if the origin be taken at a sufficiently large distance from the leading edge of the plate inside the undisturbed stream.

We have been so far discussing the boundary layer flows as plane flows where the field is identical in every plane parallel to (x, y) plane and the velocity component perpendicular to the (x, y) plane is identically zero. The simplest case in three dimensions is the axially symmetrical flow, namely, round a body of revolution. In the case when the radius of the body of revolution is much larger than the thickness of the boundary layer, Mangler(14) introduced some suitable transformations whereby the boundary layer equations take up identical forms as in two dimensions so that some known results of the two dimensional solutions can be used to predict the corresponding results of the axially symmetrical case. The general problem of the three dimensional boundary layer flows is difficult to solve, but a few interesting results may be mentioned.

When $\sigma = 1$, the terms $\frac{\partial p}{\partial x}$ and $\frac{\partial p}{\partial z}$ can be easily eliminated from the momentum and the energy equations and the resulting equation has a particular solution

$$i + \tfrac{1}{2}(u^2 + w^2) = \text{constant}. \qquad \ldots \quad (55)$$

If however $\frac{\partial p}{\partial x}$ and $\frac{\partial p}{\partial z}$ both vanish, then

$$i = A+Bu+Cw^2 \qquad \dots \quad (56)$$

corresponding to Crocco's relation.

If $\frac{\partial p}{\partial z}$ is zero but not $\frac{\partial p}{\partial x}$, then

$$i = A+Cw. \qquad \dots \quad (57)$$

Other types of problems in which the boundary layer approximations may be applied are those of laminar flows in plane jets and wakes. In the mixing zone of a jet, the pressure is approximately constant hence Von Karman-Tsien method may be used effectively to solve the problem. Pai(15) solved these equations namely the equations (45) and (46) assuming power law for viscosity and temperature relation with the help of numerical integration. Toose(16) found a closed analytic solution when μ varies as T. In this case in non-dimensional form the required equation is the equation (49). Since there is no pressure gradient in the jet, rate of flow of momentum across any transverse section of the jet is constant.

Using this result the solution of the equation (49) is

$$u_0 = \frac{1}{x_0^{1/3}} f(\zeta) \text{ where } \zeta = \frac{\psi_0}{x_0^{1/3}}$$

and $f(\zeta)$ satisfies the equation

$$f' + \tfrac{1}{8}\zeta = 0 \qquad \dots \quad (58)$$

so that $f = 1 - \frac{1}{8}\zeta^2,$

with proper choice of orifice.

Hence $u = \frac{u_1}{x^{1/3}}\left(1-\frac{1}{8}\zeta^2\right) \qquad \dots \quad (59)$

where ζ is given in terms of x and y, and u_1 is the velocity at the orifice.

The degenerate case of incompressible fluid can be deduced, as an approximation and this result is identical with the one given by Bicklay(17).

The case of axially symmetrical jet has also been solved by Pai(18) by small perturbation method or more rigorously by numerical integration. Closed analytic solution however has not been found though it exists for the case of incompressible fluid (19).

The last problem we take up is the problem of plane wake. The problem can be simplified with the assumption that the variations of velocity and temperature at a large distance downstream are small and that the heat generated by dissipation can be neglected. For the steady flow, since the pressure would be nearly constant across a section of the wake, the equations of motion and of energy can be simplified by taking

$$u = u_1(1-u_0), \qquad i = i_1\,(1-i_0) \qquad \dots \quad (60)$$

where u_0, i_0 are small compared to u_1, i_1.

The equations become

$$\rho u_1 \frac{\partial u_0}{\partial x} = \frac{\partial}{\partial y}\left(\mu \frac{\partial u_0}{\partial y}\right) \qquad \dots \quad (61)$$

and

$$\rho u_1 \frac{\partial i_0}{\partial x} = \frac{1}{\sigma}\,\frac{\partial}{\partial y}\left(\mu \frac{\partial i_0}{\partial y}\right). \qquad \dots \quad (62)$$

Using Mises's transformation and taking μ proportional to i, we get

$$\frac{\partial u_0}{\partial x} = u_1\rho_1\mu_1 \frac{\partial^2 u_0}{\partial \psi^2} \qquad \dots \quad (63)$$

and

$$\frac{\partial i_0}{\partial x} = \frac{u_1\rho_1\mu_1}{\sigma}\,\frac{\partial^2 i_0}{\partial \psi^2}. \qquad \dots \quad (64)$$

Further taking

$$\eta = \frac{\psi}{2(\mu_1\rho_1 u_1 x)^{\frac{1}{2}}}$$

we get

$$\rho v = -\,(\mu_1\rho_1 u_1 x)^{\frac{1}{2}}\eta \qquad \dots \quad (65)$$

and

$$\rho u\,dy = 2(\mu_1\rho_1 u_1 x)^{\frac{1}{2}}d\eta \qquad \dots \quad (66)$$

and the solutions of the above equations, satisfying the necessary boundary conditions are

$$u_0 = \frac{A}{\sqrt{x}}\;e^{-\eta^2} \qquad \dots \quad (67)$$

and

$$i_0 = \frac{B}{\sqrt{x}}\;e^{-\sigma\eta^2}. \qquad \dots \quad (68)$$

If D be the Drag per unit breadth of the cylindrical obstacle we have

$$D = 2\int_0^\infty \rho u(u_1-u)dy = 2Au_1^{\frac{3}{2}}\rho_1\left(\frac{\pi\nu_1}{u_1}\right)^{\frac{1}{2}}$$

and if $-2Q$ be the rate of transfer of heat from the fluid to the cylinder, we have

$$-2Q = 2\int_b^\infty \rho u(i_1 - i)dy = 2Bi_1\rho_1 u_1 \left(\frac{\pi \nu_1}{\sigma u_1} \right)^{\frac{1}{2}}.$$

To complete the solution we find the transformation equation connecting y with η.

We find from (66)

$$dy = 2\left(\frac{\nu_1 x}{u_1} \right)^{\frac{1}{2}} \frac{1 - i_0}{1 - u_0}\, d\eta = 2\left(\frac{\nu_1 x}{u_1} \right)^{\frac{1}{2}} (1 + u_0 - i_0)d\eta \quad \text{approximately}$$

hence $$y = 2\left(\frac{\nu_1 x}{u_1} \right)^{\frac{1}{2}} \eta + \frac{D}{2\rho_1 u_1^2}\, erf(\eta) + \frac{Q}{i_1\rho_1 u_1}\, erf(\eta\sqrt{\sigma}).$$

I have attempted in these few pages a brief survey of the problems of flow of real fluid. The equations are highly complicated and there is no general method of solution. Some of the simple cases have been solved luckily in closed analytic form but for the more general cases we have to have recourse to either numerical method or approximation method. There are many problems still unsolved though the corresponding cases for incompressible fluid have been solved. This branch of Fluid Dynamics provides a very interesting field for research and I hope our researchers will take more and more active interest in this line of work.

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SECTION OF STATISTICS

President : Prof. A. Bhattacharyya

Presidential Address

Some uses of the 'Amount of Information' in Statistical Inference

1. INTRODUCTION

The subject matter of this address is a description of some of the numerous uses of a quantity which was called "Amount of Information" or " Intrinsic Accuracy" by R. A. Fisher (1925) and some other quantities allied to it. This quantity was originally introduced in analytical statistics by Karl Pearson (1896) and was discussed in somo detail by him and Filon (1898). Edgeworth also considered this (1908), but it was really due to R. A. Fisher (1922) that this was placed in the forefront which it now occupies in conjunction with the principle of maximum likelihood in the theory of (point) estimation. Subsequently various authors have examined it from various points of view and have discovered new and important uses of this quantity.

It may be mentioned that information of the communication theory is different from the quantity which we here consider, although recently some interesting studies have been made which may provide a link between them.

2. HISTORY

In 1896 Pearson in his paper "Mathematical contribution to the theory of evolution III—regression, heredity and pan-mixia" considered the problem of estimation of the correlation coefficient from a bivariate normal population and determination of its probable error (Pearson's early collected papers, page 125). He applied the principle of maximum likelihood to get the "best" or the "most probable" value and also obtained for its large sample standard error (the population S.D.'s of the variables being known) an expression which is identical with the reciprocal of the "Amount of Information" regarding this parameter. This is perhaps the earliest use of this quantity which was obtained in connection with the maximum likelihood estimate. In a subsequent paper with Filon, devoted primarily to the determination of probable errors of frequency constants, the S.E.'s (standard errors) of the estimates of a large number of frequency constants involved in various frequency curves were found out and the theory of information was used throughout. However, the authors failed to realise that these S.E.'s are valid for M.L. (maximum likelihood) estimates only and Pearson did not pursue this study because of his interest in the method of moments.

Edgeworth took up the problem in 1908 and published a paper in three parts, and added an 'addendum' in 1909. In this paper he seems to have anticipated several important results subsequently rediscovered by others. He clearly realised that the S.E.'s of only the M.L. estimates (called by him the best available or the most probable) could only be obtained in terms of the 'amounts of information' and so he avoided the lapse of Pearson. He anticipated Fisher in proving that the M.L. estimates have minimum (asymptotic) variance. He writes, "It is true for the whole series that the mean square deviations from the true point, and accordingly the probable error, is less for the formula given by inversion proper than it is for the Arithmetic mean, and, by parity of reasoning, for any other rival method"—*J.R.S.S.*, 1908, page 507. He also gave a proof (communicated to him by Professor Love) of the above result which anticipated the work of Rao and Cramer about the lower bound of variances of unbiased statistics (*loc. cit.* page 662).

R. A. Fisher developed his theory in a number of papers and a recent account of his theory can be found in the sixth chapter (on the principles of estimation) of his book "Statistical Methods and Scientific Inference" (1956). In 1922 he showed that sufficient statistics have minimum limiting variance and that the method of M.L. provides us with sufficient statistics. Hence he concluded (without proof) that "The value $\sigma_{\hat{\theta}}$ so found is in these cases the least possible value for the standard deviation of a statistic designed to estimate the same parameter"—*Phil. Trans. A*, Vol. 222, page 331. This conclusion had already been reached by Edgeworth. In problems of estimation from small samples he defines efficiency not by sampling variance of the estimate but by its amount of information. In subsequent papers he proves that among some special types of estimates the M.L. estimate has the smallest limiting variance.

In 1938 Wilks considered the problem of "shortest average confidence intervals from large samples which is connected in an essential manner with the method of maximum likelihood". In collaboration with Daly (1939) he extended the result to the case of estimation of several parameters. Wald in 1941 proved that asymptotically most powerful tests of statistical hypotheses can also be obtained in a similar way and extended his result (1943) to cover the case when there are several parameters.

Aitken in collaboration with Silverstone (1941-42) considered the problem of unbiased statistics with minimum variance and with Solomon, the problem of simultaneous estimation of several parameters. Bhattacharyya (1950) extended the results of Aitken and Silverstone and gave a more general method of deriving such statistics. The problem has been considered by several other persons among whom the names of Barankin (1949) and Stein (1947) may be mentioned.

Closely related with the above problem is the problem of determination of the lower bound of the variances of unbiased estimates. Edgeworth seems to have studied the problem as early as 1908. In 1945 Rao and in 1946 Cramer independently found a lower bound of the variances of unbiased estimates, the so-called Rao-Cramer inequality. Cramer also considered the problem of simultaneous estimation and found some bounds for the concentration ellipsoid. Bhattacharyya (1946, '47) introduced certain generalised information coefficients and improved upon the Rao-Cramer inequality. Wolfowitz (1947) extended the Rao-Cramer inequality to sequential analysis and G. R. Seth (1949) did the same for Bhattacharyya inequalities.

The concept of statistical divergence has some relation with the quantity under consideration. The concept of generalised distance is due to Mahalanobis (1936). An expression of general applicability was given by Bhattacharyya (1942). Rao (1945) gave an alternative method of finding the distance between two statistical populations of the same form but differing in the values of the parameters.

This account ought to contain a reference to the interesting studies by Solomon Kullback and his associates who considered a different quantity called by them "Information" and applied it to derive many interesting and useful results. But their information is different from the classical quantity introduced by Fisher. So we do not consider that here.

We now proceed to give short descriptions of the different uses noted above.

3. DEFINITION AND GENERAL PROPERTIES

Fisher gave the name "Intrinsic accuracy of error curves" (1925) to a quantity already introduced by Karl Pearson to get the probable errors of estimates of frequency constants and discussed by Edgeworth. If the probability of a quantitative random variable lying between the values $x \pm \frac{1}{2}\,dx$ be $f(x, \theta)dx$, where θ is a parameter of the frequency (error) curve, then the intrinsic accuracy of the curve is defined as

$$I(\theta) = -\int f(x, \theta).\frac{\partial^2 \log f(x, \theta)}{\partial \theta^2}\,dx, \qquad \ldots \quad (3.1)$$

the integral extending over the whole range of possible values of the variable x. In the case of discrete variables the integration is replaced by summation. Fisher also gives the alternative form :

$$I(\theta) = \int \frac{1}{f}\left(\frac{\partial f}{\partial \theta}\right)^2 dx. \qquad \ldots \quad (3.1a)$$

It is evident that these two expressions can not be identical unless we assume some conditions regarding the limits of integration or the terminal values of the error function and its derivative with respect to θ. The simplest condition is that the range of the variable x is independent of the parameter θ and unless otherwise stated we shall consistently assume this condition throughout. The above expressions can be simply written as

$$I = E\left(-\frac{\partial^2 \log f}{\partial \theta^2}\right) = E\left(\frac{1}{f}\ \frac{\partial f}{\partial \theta}\right)^2, \qquad .. \quad (3.2)$$

where E is the symbol of mathematical expectation. In the case of multivariate error functions, the intrinsic accuracy is given by the expression (3.2). A more appropriate name which has perhaps been more often used by Fisher is the "Amount of Information" contained in the random variable (s) respecting the parameter θ.

In the case of multiparametric frequency functions involving parameters θ_i, $i = 1, 2, \ldots$, we get the information matrix $((I_{ij}))$ where

$$I_{ij} = E\left(\frac{1}{f^2} \cdot \frac{\partial f}{\partial \theta_i} \cdot \frac{\partial f}{\partial \theta_j}\right) = - \left(\frac{\partial^2 \log f}{\partial \theta_i\, \partial \theta_j}\right). \qquad \ldots \quad (3.3)$$

These quantities possess some important and interesting properties.

(A) The amount of information contained in a number of independent variables is the sum of the amounts of information contained by them separately. In the case of multiparametric distributions, the information matrix of a number of independent variables is the sum of their individual information matrices. As a corollary we get that the information matrix in a random sample of size n drawn independently from a population is n-times the information matrix of a single variable.

(B) The amount of information contained in a statistic calculated from a sample can not exceed that contained by the sample itself. Except in the case of sufficient statistics there is always loss of information by the use of statistics calculated from samples.

(C) The amount of information contained in a number of random variables is invariant under any change of the random variables (the transformation should not involve the parameters).

(D) The amount of information in respect of a function $\phi(\theta)$ of the parameter θ is given by

$$I_\phi = \left(\frac{d\theta}{d\phi}\right)^2 I_\theta, \qquad \ldots \quad (3.4)$$

and in the case of many parameters the information matrix of the transformed parameters $\phi_1, \phi_2, \ldots$ is given by

$$\left(\left(I_\phi\right)\right) = \left(\left(\frac{\partial\theta_i}{\partial\phi_j}\right)\right)' \left(\left(I\right)\right) \left(\left(\frac{\partial\theta_i}{\partial\phi_j}\right)\right). \qquad \ldots \quad (3.5)$$

Bhattacharyya (1946, '47) introduced certain generalised information coefficients and we shall briefly discuss their uses in section 8.

4. MAXIMUM LIKELIHOOD (M. L.)

The principle of maximum likelihood is one of the oldest methods of estimation. However, Karl Pearson first tried to find the S.E. of the M.L. estimate of the coefficient of correlation. He then with Filon gave a general method of getting the large sample S.E.'s of estimates of frequency constants. He virtually proved that if $\hat{\theta}_i$ be the estimate of the parameter θ_i, then in large samples the estimates tend to follow the multivariate normal distribution with frequency function

$$\text{Constant. Exp}\ \{-\tfrac{1}{2}\Sigma \Sigma\ I_{ij}\ (\hat{\theta}_i-\theta_i)\ (\hat{\theta}_j-\theta_j)\}, \qquad \ldots \quad (4.1)$$

where $((I_{ij}))$ is the information matrix of the sample. The lapse in Pearson was that he did not realise that $\hat{\theta}_i$ should be M. L. estimates. Edgeworth was however free from this lapse. He also proved that if T be the unbiased estimate of the location parameter θ, then

$$V(T) \geqslant \frac{1}{I(\theta)}, \quad [\textit{J.R.S.S.}, \text{1908, page 662, and 1909, page 81}] \qquad \ldots \quad (4.2)$$

$I(\theta)$ being the amount of information in the sample. This is the so-called Rao-Cramer inequality (8.1) which we shall consider in a subsequent section.

Fisher considered the problem of estimation in detail in a series of papers (1922, '25, '35, '56). His theory of estimation is based on two props:—the main prop is sufficient statistics and the alternative one is the principle of maximum likelihood. The discovery of sufficient statistics is one of the most important advances in theoretical statistics. When such a statistic exists, it should be used in all inductive inferences. They can be proved to possess minimum variances and they can be obtained by the method of maximum likelihood. In their absence M.L. estimates have to be used. Besides having great intuitive appeal, these estimates possess some limiting properties. According to Fisher, the two criteria which a good estimate should satisfy are (i) Consistency and (ii) Efficiency. As there is some difficulty in defining these criteria, Fisher originally considered the problem in two stages—the large sample set-up and the small sample set-up.

Fisher himself admits (1956) the difficulty in defining the term consistency. His original definition is that the statistic T is a consistent estimate of the parameter θ if it converges in probability to the parameter as the sample size is increased. A consistent statistic is efficient if it has minimum limiting variance. Fisher then proves that in the case of frequency data "the equations of Maximum Likelihood are indeed the only equations of estimation, linear in the observed frequencies, which are efficient with large samples " (1956). These estimates are locally consistent. For the variance of the M.L. estimate he gets

$$V(\hat{\theta}) = \frac{1}{nS\left\{\frac{1}{p_j}\left(\frac{\partial p_j}{\partial \theta}\right)^2\right\}} \qquad \ldots \quad (4.3)$$

For small samples he defines a consistent statistic (applicable to frequency data) as "a function of the observed frequencies which takes the exact parametric value when for these frequencies their expectations are substituted." "It is the amount of information, and not the sampling variance, which completes the criterion of efficiency for finite samples, for when the distribution is not Normal the variance is an imperfect measure of precision." But Fisher did not prove that the M.L. estimates are efficient in finite samples and remarked, "I do not know of a general proof, but no exception has been found to the rule that among Consistent Estimates when properly defined, that which conserves the greatest amount of information is the estimate of maximum likelihood."

As M. L. equations are often difficult to solve, we can use a trial value θ' (an inefficient estimate) of the parameter, principally with a view to its being near to the final solution and get the improved solution,

$$\theta'' = \theta' + \frac{1}{I(\theta')} \sum_{i=1}^{n} \frac{\partial \log f(x_i, \theta')}{\partial \theta'}, \qquad \ldots \quad (4.4)$$

where I is the amount of information in the sample and x_i, $i = 1, 2, \ldots n$ are the sample observations. Usually one iteration is sufficient to give efficient estimate, although we can check the result by repeating the calculation with this improved result. With many parameters, starting from a set of trial values (θ') we can get improved estimates which can be expressed in matrix notation as follows

$$(\theta'') = (\theta') + ((I_{ij}))^{-1} \left(\sum \frac{\partial \log f(x_i, \theta')}{\partial \theta'}\right) \qquad \ldots \quad (4.5)$$

where $((I_{ij}))$ is the information matrix of the sample in which (θ') is put for (θ).

Hardly any new result has been added to what Fisher had found out. It is true that M.L. estimates are not always consistent. In this respect the researches of Huzurbazar (1948) and Chanda (1954) are important. They have shown that in large samples, under some regularity conditions, the M. L. estimates converge in probability to the population parameters if the ranges of the stochastic variables are independent of the parameters. The result (4.1) originally due to K. Pearson was the subject of study by Doob (1934), Cramer (1946) and many other workers. Wald (1949) gave a set of conditions under which it holds.

Small sample problem has not received the attention of research workers to that extent which it deserves.

5. TESTING OF HYPOTHESIS (LARGE SAMPLE)

The results are mainly due to Wald. He first defines what an asymptotically most powerful test is and then proceeds to find the critical regions. In the case of a single parameter he proves (1941) that, if $\hat{\theta}_n$ be the M.L. estimate of θ from a sample of size n, then the critical region M_n obtained from the inequility $(\hat{\theta}_n-\theta_0) \geqslant A_n$, where A_n is so chosen that $P_r\{M_n | \theta_0\} = \alpha$, provides an asymptotically most powerful test for the hypothesis $H_0(\theta = \theta_0)$ against alternative hypotheses $H'(\theta > \theta_0)$. Since $(\hat{\theta}_n-\theta_0)$ tends to be distributed normally with variance $\frac{1}{I}$, the value of A_n can be found from the normal table. In a subsequent paper he has pointed out that the asymptotic critical region can be obtained more simply from the inequality

$$\sum_{i=1}^{n} \frac{\partial \log f(x_i, \theta_0)}{\partial \theta_0} \geqslant A_n. \qquad \ldots \quad (5.1)$$

The constant A_n can be obtained from the normal table. In 1943 he considered the problem of several parameters and simple and composite hypotheses involving them.

If the k unknown parameters be $\theta_1, \theta_2, \ldots \theta_k$, then to test the hypothesis

$$\xi_1(\theta_1, \theta_2, \ldots \theta_k) = \xi_2(\theta_1, \theta_2, \ldots \theta_k) = \ldots = \xi_r(\theta_1, \theta_2, \ldots \theta_k) = 0,\ r<k, \quad \ldots \quad (5.2)$$

we use the asymptotically most powerful critical region W_n given by

$$\sum_{q=1}^{r} \sum_{p=1}^{r} \xi_p(\hat{\theta}_1, \hat{\theta}_2, \ldots \hat{\theta}_k)\, \xi_q(\hat{\theta}_1, \hat{\theta}_2, \ldots \hat{\theta}_k)\, C_{pq} \geqslant d_n, \qquad \ldots \quad (5.3)$$

where $\hat{\theta}_i$ is the M.L. estimate of the parameter θ_i based on n independent observations and

$$((C_{pq}))^{-1} = \left(\left(\frac{\partial \xi_p}{\partial \theta_i}\right)\right)' \left(\left(I_{ij}\right)\right)^{-1} \left(\left(\frac{\partial \xi_p}{\partial \theta_i}\right)\right). \qquad \ldots \quad (5.4)$$

In matrix notation $((C_{pq}))$ is a $r \times r$ matrix, $\left(\left(\frac{\partial \xi_p}{\partial \theta_i}\right)\right)$ is a $r \times k$ matrix and $((I_{ij}))$ is the $k \times k$ information matrix of the sample with respect to the parameters. The likelihood ratio test (*i.e.* λ-test) of Neyman and Pearson also yields asymptotically most powerful test and the critical region L_n is obtained by

$$\lambda_n \leqslant \bar{\lambda}_n, \qquad \dots \quad (5.5)$$

where λ_n is the likelihood ratio statistic for the above hypothesis. The quantity on the left side of (5.3) has the same asymptotic distribution as $-2 \log \lambda_n$ which is the same as the χ^2-distribution with r degrees of freedom when the null hypothesis is true (Wilks, 1938).

6. CONFIDENCE INTERVAL FOR LARGE SAMPLES

In 1938 Wilks found the shortest average confidence interval for a parameter for large samples. The fiducial limits for θ are found for a given confidence coefficient $1-\alpha$ by setting

$$\frac{1}{\sqrt{I}} \frac{\partial L}{\partial \theta} = \pm \psi(\alpha), \qquad \dots \quad (6.1)$$

where $L = \sum_{i=1}^{n} \log f(x_i, \theta)$ is the logarithm of the likelihood function of the sample and I is the amount of information. $\psi(\alpha)$ is the value of the normal deviate corresponding to the level of significance α. Later on he, in collaboration with Daly, found the optimum fiducial region for several population parameters from large samples (1939). The fiducial region is obtained in the form

$$\sum_{i,j} I^{ij} \left(\frac{\partial L}{\partial \theta_i}\right)\left(\frac{\partial L}{\partial \theta_j}\right) \leqslant \chi^2_\alpha, \; ((I^{ij})) = ((I_{ij}))^{-1}. \qquad \dots \quad (6.2)$$

These results are of course valid under some regularity conditions.

In 1942 Wald also considered the same problem and proved that the confidence interval of Wilks is asymptotically shortest compared with any arbitrary confidence interval without any restriction to a certain class of functions considered by him.

M. S. Bartlett (1953, '55) found the higher moments of $\frac{\partial L}{\partial \theta}$ and adjusted for the skewness in it. He recommended

$$T(\theta) = \frac{\partial L}{\partial \theta} - \frac{1}{6} \frac{k_3}{I^2} \left\{\left(\frac{\partial L}{\partial \theta}\right)^2 - I\right\} \qquad \dots \quad (6.3)$$

to be normal with zero mean and variance I, and gave the confidence interval as

$$\frac{T(\theta)}{\sqrt{I}} = \pm\, \psi(\alpha). \qquad \dots \quad (6.4)$$

He also considered the problem of nuisance parameters and how to get rid of them. He applied his method to the study of the Fisher-Behren's and Welch's tests.

7. UNBIASED STATISTICS WITH MINIMUM VARIANCE

The method of estimation, now called the principle of linear estimation and introduced by Gauss and Markoff, is based on finding linear functions of the random variables which are unbiased and of minimum variance. This is an old method and has intuitive appeal. The original form of Fisher's criteria of consistency and efficiency are limiting concepts of unbiasedness and minimum variability. This method has two main objections :—(1) if T is an unbiased estimate of θ, then $\phi(T)$ is not usually an unbiased estimate of $\phi(\theta)$; (2) in many distributions the parameter θ may not possess an unbiased estimate.

Aitken in collaboration with Silverstone (1941-42) made an attempt to get UMVS (unbiased statistics with minimum variance). He showed that if

$$T = \theta + \frac{1}{I(\theta)}\,\frac{\partial L}{\partial \theta} \qquad \dots \quad (7.1)$$

be free from the parameter θ, then it provides us with an UMVS. In this case T is a sufficient statistic. Bhattacharyya (1950) extended the result and showed that if f be the frequency function of the sample, then the statistic

$$T = \lambda_0 + \frac{1}{f}\,\Sigma\, \lambda_i\, \Phi_i \qquad \dots \quad (7.2)$$

when free from the parameters will provide us with UMVS. Here λ's are certain determinable quantities dependent on the population parameters and Φ's are some functions of the random variables and the parameters derivable from the frequency function f with the help of differential and integral calculus or some other finite calculus. Closely associated with this problem is the problem considered in the next section.

8. LOWER BOUNDS OF THE VARIANCES OF UNBIASED STATISTICS.

This problem was considered by Edgeworth and Fisher. Rao (1945) and Cramer (1946) independently proved that if T is a statistic having expectation $\tau(\theta)$, then under some regularity conditions

$$V(T) \geqslant \frac{1}{I(\theta)}\left(\frac{d\tau}{d\theta}\right)^2. \quad \text{[Rao-Cramer inequality]} \qquad \dots \quad (8.1)$$

The sign of equality holds in the case of distributions admitting sufficient statistics. When there are more than one parameter, if T_i be an unbiased statistic for θ_i, then

$$V(T_i) \geqslant I^{ii}, \qquad ((I^{ij})) = ((I_{ij}))^{-1}. \qquad \text{[Rao]} \qquad \ldots \quad (8.2)$$

For simultaneous estimation Cramer proved that the concentration ellipsoid of a set of unbiased statistics of the k parameters θ_1, $\theta_2, \ldots \theta_k$ contains within itself the ellipsoid

$$\sum_{i=1}^{k} \sum_{j=1}^{k} I_{ij}(u_i-\theta_i)(u_j-\theta_j) = k+2.$$

In 1946 Bhattacharyya improved upon the inequality (8.1). He introduced certain quantities termed generalised information coefficients. They are defined by

$$J_{\iota\iota'} = E\left(\frac{1}{f^2}\frac{\partial^\iota f}{\partial\theta^\iota}\frac{\partial^{\iota'} f}{\partial\theta^{\iota'}}\right), \qquad \ldots \quad (8.3)$$

and the Fisherian information is $J_{11} = I$. The Bhattacharyya inequality is

$$V(T) \geqslant \Sigma \quad \tau^{(\iota)}\tau^{(\iota')}J^{\iota\iota'}, \qquad \ldots \quad (8.4)$$

where $\tau^{(\iota)} = \frac{d\tau^\iota}{d\theta^\iota}$, $((J^{\iota\iota'})) = ((J_{\iota\iota'}))^{-1}$ and ι, ι' taking values from 1 to any positive integer r. When $r = 1$, we get (8.1). When $r = 2$, we get

$$V(T) \geqslant \frac{1}{J_{11}}\left(\frac{d\tau}{d\theta}\right)^2 + \frac{\left(\frac{d\tau}{d\theta}\cdot J_{12} - \frac{d^2\tau}{d\theta^2}\cdot J_{11}\right)^2}{J_{11}(J_{11}\,J_{22}-J_{12}^2)}$$

which gives an idea about the improvement. By using larger and larger values for r we can go on improving upon the result. In this case the sign of equality holds when $T.f = \lambda_0 f + \lambda_1 f^{(1)} + \lambda_2 f^{(2)}$, which is a special case of (7.2). R. C. Davis (1951) has shown that in this case the frequency function must admit a sufficient statistic. When applied to the Cauchy distribution with location parameter θ and unit scale parameter, the unbiased statistic for θ has a variance

$$V(T) > \frac{2}{n} + \frac{6}{n(2n^2+6n+7)}.$$

When applied to the Binomial distribution with probability p and sample size n, the unbiased statistic T for the parameter $\tau(p)$ can be proved to satisfy the relation

$$V(T) = \sum_{i=1}^{n} \frac{(pq)^i}{i\,!\binom{n}{i}} \cdot \left(\frac{d^i\tau}{dp^i}\right)^2.$$

In the case of multiparametric distributions involving k parameters $\theta_1, \theta_2, \dots \theta_k$ we can define the set of generalised information coefficients involving partial derivatives of the frequency function with respect to these parameters. Thus if $\iota = (i_1, i_2, \dots i_k)$ and $\iota' = (i'_1, i'_2, \dots i'_k)$ be two ordered sets of non-negative integers, then we write

$$J_{\iota\iota'} = E\left\{\frac{1}{f^2}\frac{\delta^{i_1+i_2+\dots+i_k}f}{\delta\theta_1^{i_1}\,\delta\theta_2^{i_2}\dots\,\delta\theta_k^{i_k}}\cdot\ \frac{\delta^{i'_1+i'_2+\dots+i'_k}f}{\delta\theta_1^{i'_1}\,\delta\theta_2^{i'_2}\dots\,\delta\theta_k^{i'_k}}\right\}. \quad \dots \quad (8.5)$$

Similarly we write

$$\tau^{(\iota)} = \frac{\delta^{i_1+i_2+\dots i_k}\tau}{\delta\theta_1^{i_1}\,\delta\theta_2^{i_2}\dots\,\delta\theta_k^{i_k}}.$$

Then the inequality (8.4) remains valid if these quantities be put in them. The equality sign holds if

$$T\,.\,f = \lambda_0 f + \Sigma\,\lambda_\iota f^{(\iota)}, \quad \iota = (i_1, i_2, \cdots i_k), \qquad (8.6)$$

which is a special case of (7.2). The most general form of the inequality of which (8.4) is a special case can be stated as follows. T is a statistic and $f_0, f_1, \dots f_l$ are $l+1$ frequency functions: Let the mathematical expectations of T with respect to these be $\tau_0, \tau_1, \dots \tau_l$ respectively. Then the variance of T with respect to f_0 satisfies the inequality

$$V_0(T) \geqslant \sum_{i,j=1}^{l} (\tau_i - \tau_0)(\tau_j - \tau_0)K^{ij}, \text{ where } ((K^{ij})) = ((K_{ij}))^{-1}$$

and

$$K_{ij} = E_0\left\{\frac{(f_i - f_0)(f_j - f_0)}{f_0^2}\right\},$$

the expectation being with respect of f_0.

An interesting study by Barankin (1949) about locally best unbiased estimates contains a result which can be identified with (8.7) in the special case when the variance is used for judging the statistics. Charles Stein has also considered Unbiased Estimates with Minimum Variance (1947). J. Kiefer (1952), D.A.S. Fraser and Guttman (1952), Chapman and Robbins (1951) have also considered the problem. However, no fundamentally new results were given.

9. LOWER BOUNDS IN SEQUENTIAL SAMPLING

In 1947 Wolfowitz extended Rao-Cramer inequality to sequential sampling and showed that the results remain true if ordinary information coefficients are replaced by modified expressions. In sequential sampling the information coefficients take the form

$$I_{ij} = En.E\left(\frac{\partial \log f}{\partial \theta_i} \cdot \frac{\partial \log f}{\partial \theta_j}\right).$$

Similarly Bhattacharyya inequalities were extended to sequential sampling procedure by G. R. Seth (1949). The generalised information coefficients are modified as follows :

$$J_{ii'} = En.E\left\{\frac{1}{f^2}\frac{\partial^{i_1+i_2+\cdots i_k} f}{\partial\theta_1^{i_1}\partial\theta_2^{i_2}\ldots\partial\theta_k^{i_k}} \cdot \frac{\partial^{i'_1+i'_2+\cdots+i'_k} f}{\partial\theta_1^{i'_1}\,\partial\theta_2^{i'_2}\ldots\partial\theta_k^{i'_k}}\right\}.$$

10. STATISTICAL DIVERGENCE

Mahalanobis considered the problem of generalised distance in statistics in 1936. If Δ be the generalised distance between two normal populations with means (m_i) and (m_i+dm_i) and the same covariance matrix, then

$$(d\Delta)^2 = \Sigma\ \Sigma\sigma^{ij}\ dm_i dm_j,$$

and integrating he gets the distance as

$$\Delta^2 = \Sigma\ \Sigma\ \sigma^{ij}(m_i-m_i')(m_j-m_j')$$

between two normal populations with means (m_i) and (m_i'). Pursuing the trend of argument Rao (1945) starts from the relation

$$(d\Delta)^2 = \Sigma\ \Sigma\ I_{ij}d\theta_i d\theta_j \qquad \ldots \quad (10.1)$$

and integrating over a geodesic in the parametric space gets the distance between two populations having the same form of frequency functions differing in the values of the parameters.

Another earlier approach to the general problem was by Bhattacharyya (1942). The generalised distance was defined by

$$\Delta = \cos^{-1}\int\int\ldots\int \sqrt{f_1 \cdot f_2}\ dv$$

where dv is the elementary volume in the sample space, the integral extending over the entire sample space. From the relation

$$4\sin^2\frac{\Delta}{2} = \int\int\ldots\int (\sqrt{f_1}-\sqrt{f_2})^2 dv$$

we get in the case of frequency functions with the same form but differing infinitesimally in the values of the parameter the relation (10.1) except for a constant factor $\frac{1}{4}$ on the right hand side.

11. Solomon Kullback and Leibler (1951) considered some quantity which they called 'information' on a random variable for discrimination between two hypotheses. They also considered 'mean information' and also divergence'. They proved that in the parametric case, the mean information between two hypotheses differing by infinitesimal amount in respect of the values of the parameters involved is $\frac{1}{2} \Sigma \Sigma I_{ij} \delta\theta_i \cdot \delta\theta_j$ and the divergence is twice this quantity. Kullback has also applied (1952, '54) the theory to multivariate analysis. However, as this theory differs from the classical Fisherian theory, we do not consider it in this short account.

We have given a short account of some of the uses of the intersting and important quantity called by Fisher 'Amount of Information' and some of its analogues. The account is far from complete and there are numerous gaps. The literature is also quite extensive. It is difficult to do justice to the subject in such a short account and I have simply drawn the attention of workers in this subject to this important quantity. I leave the task of giving a proper account to my able successors.

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SECTION OF PHYSICS

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Presidential Address

ELASTIC WAVE PROPAGATION IN FLUIDS

I. INTRODUCTION

I would like to place before you the present day problems and the suggested solutions of an ageold branch of Physics, namely, the propagation of elastic waves in a fluid medium. The problems have cropped up during the recent period of only about two decades, on account of the newly developed technique of Ultrasonic measurements. With comparatively much smaller wavelengths than those of the accoustic waves, one is now in a position to take somewhat accurate measurements of many of the propagation characteristics of the elastic waves. Such measurements were not possible, before, with the long wavelength accoustic waves. Inspite of the earlier experimental limitations, however, the subject has been of absorbing interest from very old times, and many important theoretical relations regarding elastic wave propagation, had been worked out by such stalwarts of Science as Newton and Laplace, Rayleigh, Stokes and Lamb, even without having the opportunity to test some of these propositions.

The chief points of interest about the characteristics of a wave propagation are its velocity and attenuation in different media and I would limit myself here, to these aspects, and also to the property of the flow of the medium that has been observed to be associated with the wave propagation.

The Newtonian relation for velocity,

reducing to

$$\left.\begin{aligned} V^2 &= dp/d\rho, \\ V^2 &= \gamma p/\rho, \end{aligned}\right\} \qquad \ldots \quad (1)$$

in the case of gases, may be taken as the starting point for velocity relation. The known values of γ, p, and ρ immediately gives us the velocity in the gaseous medium, which is confirmed by experimental tests. There is nothing in the relation to suggest any dependence of the velocity on the frequency, nor it had been observed. In the case of the liquids, however, no explict form of relationship to determine the velocity, had been worked out. We have to satisfy ourselves with the theoretical relations,

$$\left.\begin{aligned} &V^2 = dp/d\rho \\ \text{or} \quad &V^2 = 1/\rho\beta_a, \end{aligned}\right\} \qquad \dots \quad (2)$$

where β_a is the adiabatic compressibility. None of these relations can be utilised to calculate the velocity on known observational data. Further, on the basis of the applicability of Hooke's stress-strain relation, the velocity should be independent of frequency. Due to obvious difficulties, the velocity determination of accoustic waves in liquids, was confined only to the measurements in water, until the advent of the supersonic period.

As regards the attenuation of elastic waves in fluid media, it was shown by Stokes (1840), that starting from the general equation of fluid motion in a viscous medium, in the form,

$$\rho \frac{du}{dt} + \Delta p - \eta/_3\, \Delta\Delta u - \eta\Delta^2 u = 0, \qquad \dots \quad (3)$$

along with the auxiliary relations about continuity, and of accoustic velocity and condensation, one may easily obtain the Stoke's equation in viscous medium as,

$$\frac{d^2\xi}{dt^2} - c^2 \frac{d^2\xi}{dx^2} - \frac{4\eta}{3\rho_0} \cdot \frac{d^3\xi}{d^2x dt} = 0 \qquad \dots \quad (3a)$$

where u is the velocity of the medium, η its viscosity, and ξ represents the displacement. With ξ of periodic nature, one obtains from the above, that there would be an absorption coefficient, α, per unit distance, determined by the relation,

$$\frac{\alpha}{\nu^2} = \frac{8\pi^2\eta}{3\rho_0 c^3} \qquad \dots \quad (4)$$

If the velocity in the fluid medium is known, the absorption coefficient can be easily calculated with the help of the other known values.

Kirchhoff (1868) had also proposed an attenuation of the elastic waves, arising from a different cause, namely, the conductivity of the medium. It was considered that heat energy was conducted away from the compressional regions of the medium to other regions and vice versa, giving us a resultant absorption coefficient obtainable in the form,

$$\frac{\alpha}{\nu^2} = \frac{2\pi^2}{\rho c^3} \cdot \frac{\gamma - 1}{C_p} \cdot K, \qquad \dots \quad (4a)$$

where K is the thermal conductivity of the medium. The absorption coefficient, so calculated, comes to a much lower order than that by Stokes relation, particularly in the case of the liquids. The theoretical values of the absorption coefficients, so calculated, could not, however, be tested with accoustic waves, and the theories remained to be tested at later periods, only by the ultrasonic waves.

Associated with these two main characteristics of the elastic wave propagation, one finds an unpredicted property of the flow of the medium, which was critically considered by Lord Rayleigh (1883) in his experiments with Kundt's tube. Such a flow of the medium had not been theoretically, foreseen, nor a satisfactory theory could be put forward even by Lord Rayleigh (1886), to explain the observed characteristics of the flow. As a matter of fact, the flow of the medium has not been properly studied since then, and although vigorous theoretical attempts are being made, in recent times, to understand this aspect of the elastic wave propagation, it must be said that these characteristics are not yet fully understood.

2. DISPERSION, ABSORPTION AND RELAXATION MECHANISM IN GASES

We come, now, to the discussion of the problems which have cropped up with the advent of ultrasonic methods. Firstly, we may state that it has been observed that the ultrasonic velocity in a gaseous medium changed from a particular lower value to a higher value as the frequency is increased. The change for Carbon-di-oxide, the most strongly irregular gas, was about 4% only, (Kneser,1931), as we increase the frequency, in the region of 10^5 cycles per second. Such a dispersion with frequency was not expected by classical relations, as has been already pointed out. It had been proposed by Herzfeld and Rice (1928), Kneser (1931) as also by Rutgers (1933), that the dispersion in gases was caused by an excitation-relaxation mechanism. It suggests that the fundamental ground for the change of velocity with frequency was a time lag between the energy impressed by the sound waves and the internal energy of the medium in the form of oscillatory motion. It is proposed that the general thermodynamic relationship

$$C\,dT + p\,dv = 0,$$

should be written as $C_a\,dT + C'_i\,dT + p dv = 0$ ... (5)

where C is the specific heat at constant volume, $C'_i\,dT$ denotes the change in energy due to assimilation in the internal degrees of freedom and $C_a\,dT$ denotes the change in energy on account of translatory motion, etc. Considering $C'_i\,dT$ as a function of the frequency, which naturally, it should be, on account of the time required for conversion from one form of energy to the other, we would have,

$$C_a dT + C_i F(w) dT + pdv = 0 \qquad \ldots \quad (5a)$$

When we consider the wave velocity relation,

$$V^2 = \frac{dp}{d\rho} = \frac{p}{\rho} \left\{ 1 - \frac{d(pv)}{pdv} \right\} \qquad \ldots \quad (6)$$

and

$$F(\omega) = \frac{1}{1+i\omega/(K_1+K_0)} = \frac{1}{1+i\omega\beta} \qquad \ldots \quad (7)$$

from consideration of transition from 0-th state to the 1-th state and vice versa, with K_0 and K_1 as the number of transitions per second, we have the real part of V^2, expressed as,

$$V^2 = \frac{p}{\rho} \left(1+R \cdot \frac{C+\omega^2\beta^2 C_a}{C^2+\omega^2\beta^2 C_a^2} \right) \qquad \ldots \quad (8)$$

where $F(0)$ and $F(\infty)$ have been considered to be unity and zero respectively. It gives us the values of the low frequency and high frequency velocities related as

$$\frac{V^2_\infty}{V_0^2} = \frac{C_a+R}{C_a} \times \frac{C}{C+R} \,. \qquad \ldots \quad (9)$$

with $C = C_a + C_i$. A particular excitation to a known oscillatory state would enable one to determine the C_i value from the Einstein function,

$$C_i = \frac{\theta^2 \,.\, e^\theta}{(e^\theta - 1)} \,.\, (R \text{ units}) \qquad \ldots \quad (10)$$

where θ is the abbreviation for $h\nu/KT$. This would also determine the value of C_a, from the known value of the specific heat at constant volume, C.

It may be stated now, that associated with the dispersion by relaxation mechanism, there would be an increased value of the absorption coefficient, μ per unit wavelength, in the region of relaxation frequency, which gives rise to an increased and constant value of α/ν^2 in the lower frequency region, dropping down through the relaxation frequency to a low value, for regions of higher frequency, as explained later. Such increased values of α/ν^2 in the lower frequency regions or of the absorption coefficient per unit wavelength at the relaxation frequency region, have been observed for gases. The experimental data for the strongly absorbing Carbondioxide (Grossmann, 1932), however, do not correspond to the requirement of the theory.

3. ABSORPTION DATA AND RELAXATION MECHANISM FOR LIQUIDS

The new observational data, on liquids are much more intriguing. It has been found that the measured attenuation coefficients in diferent liquids are largely at variance with the attenuation coefficient calculated from the theoretical relation of Stokes, although a constant value of $\frac{\alpha}{\nu^2}$ is generally obtained, as required by Stokes relation. The nature of the variations is also very peculiar (Pinkerton 1949). Highly viscous liquids like Castor oil and glycerine have their measured high values of α/ν^2 in good agreement with the Stoke's relation (Hunter, 1941). So also is the low value for Mercury (Ringo, Fitzgerald and Hurdle, 1947). The group of associated liquids like water and alcohols, has their experimental α/ν^2 values as much as 2 to 3 times the value calculated by Stoke's relation (Pellam and Galt, 1946). In the case of most of the other organic liquids the experimental values are much larger than the values calculated from Stoke's relation. The observed values range from an order of about 10 times the Stokes value, in liquids like Xylene and Toluene to more than 120 times in the case of Benzene, reaching the largest divergence for Carbon-disulphide, where the observed value is as high as about 1400 times the calculated value. The calculated Stoke's values for most of these non-viscous organic liquids come in the rage of 5 to 10×10^{-17} C. G. S units. Besides, the liquid acetic acid and acetates obtain (Pinkerton, 1948) a very high value of the absorption coefficient, giving $\frac{\alpha}{\nu^2}$ values as nearly 1000 times the Stokes value, at about 10^6 cycles per second, which drops down rapidly to a low value at higher frequencies. These very abnormal behaviours of the propagation characteristics are, even to this day, not very clearly understood and constitute, therefore, a problem of major interest in the dynamical theory of elastic wave propagation.

In an attempt to explain the anomaly in the case of the liquids, Lucas and Biquard (1937), and Clayes, Errera and Sack (1937) suggested an elastic heterogenity in the medium and a quasi-crystalline structure of the liquid respectively. The procedures, however, failed to explain the characteristics and the trends of thought on these lines were discarded.

In view of the more or less satisfactory explanation of the anomalous dispersion and absorption in gases, it had been suggested by Dutta and Ghose (1937-39), as also by Kneser (1938), that an excitation relaxation mechanism might as well be responsible for the very high absorption observed in many of the liquids. The liquids should then have obtained the associated dispersion in the region of the relaxation frequency. The gas dispersion formula was modified by Dutta (1936-37), by putting

$$d(pv)_s^s = dH - dE = (C_p - C_v)\,dT = (\alpha_s^2 V_m T/\beta_s)\,dT \quad \ldots \quad (11)$$

in place of RdT, used in the gas equation, where α_e and β_a denote the co-efficients of expansion and compressibility for the liquids. It gives us the relation, for V^2_∞/V_0^2, in the case of the liquids in the form,

$$V^2_\infty/V_0^2 = \frac{C_a^2 + \alpha_e^2 V_m T/\beta_a}{C_a} \times \frac{C}{C + \alpha_e^2 V_m T/\beta_a} \qquad \ldots \quad (12)$$

With the known values of the specific heat at constant pressure, as also of $C_p - C_v$, obtained from $\frac{\alpha_e^2 V_m T}{\beta_a}$, one can easily determine the magnitude of the expected dispersion, when the value of C_i for a particular mode of excitation is calculated. Taking the Raman and Infrared frequencies, the values of C_i have been calculated by Dutta. The expected magnitude of dispersion for most of the organic liquids is in the range of 1 to 2 per cent, and this amount is of a measurable order. It is, however, calculated to be insignificantly small for water. Such dispersion has not been established for these liquids, in the frequency range upto about 10^8 cycles per second, although various workers have worked on the problem.

It is possible, however, that the relaxation frequency is of a still higher order and the high value of α/ν^2 in the lower frequency region, is caused by any of these excitation relaxation mechanisms. When one calculates the absorption coefficient from the complex velocity expression, one obtains,

$$\alpha/\nu^2 = \frac{2\mu_m}{V.\,\nu_m} \quad \frac{1}{1 + (\nu/\nu_m)^2} \qquad \ldots \quad (13)$$

and

$$\mu = 2\mu_m \frac{\nu/\nu_m}{1 + (\nu/\nu_m)^2} \qquad \ldots \quad (14)$$

where α is the absorption coefficient per unit length, μ is that per unit wavelength, ν_m is the relaxation frequency and μ_m is the value of μ at ν_m, and may be obtained in the form

$$\mu_m = \pi \,.\, \frac{(V^2_\infty - V_0^2)}{V_0^2}. \qquad \ldots \quad (15)$$

The value of μ_m may be predetermined with the help of the relation (12). The formulae show that the μ value obtains a maximum at the frequency value of ν_m, dropping on both sides, and α/ν^2 would have a constant higher value at low frequencies, dropping down to a small value, as ν increases beyond ν_m.

When, however, an estimate of the μ_m value is obtained for a selected mode of excitation, the relation for α/ν^2, given above, immediately settles the value of ν_m, for the particular relaxation mechanism, as the velocities have been determined for most of the liquids (Parthasarathy, 1935, 1936).

The data for highly absorbing Carbon-di-sulphide fixes up from the possible C_i values, the maximum possible relaxation frequency at 3×10^7 cycles per second, where a dispersion should have been observed. No such dispersion has been noted for Carbon-di-sulphide in this region, nor a drop in α/ν^2 value is known to occur here. Moreover, the attempt to explain the extra large absorption in Carbon-di-sulphide with a simultaneous application of a number of vibratory modes, brings in the question as to why a similar procedure should not be applied for other liquids also, bringing their expected attenuation to nearly as high values, which are not observed.

It has already been pointed that with the associated groups like water, no dispersion is expected by relaxation mechanism, on account of the very low C_i value as also of '$C_p - C_v$' value. This would, therefore, have no absorption due to excitation relaxation mechanism. An absorption of about 3 times the Stokes value has, however, been observed. Hall's (1948) suggestion of a structural relaxation mechanism, in such cases, puts off the difficulty for the associated system of water. Attempts to explain absorption in other associated liquids on a similar basis, however, fails (Sette, 1950).

Further, it is worth consideration that in the series of liquids Benzene, Toluene, and Xylene, although no particularly strong new spectroscopically determined vibrational frequency for Benzene, in comparison with the other two liquids, has been known, a large difference occurs in their experimental absorption coefficients. This cannot be understood on a critical consideration of the comparative data with regard to the theory of excitation relaxation.

As for the group of liquids headed by acetic acid, the peculiar behaviour of a large drop in α/ν^2 value, unassociated with accompanying dispersion, in the region of a megacycle frequency, is again confusing from the excitation relaxation mechanism. Associated with this, a very high value of α/ν^2 in the lower frequency region, with the magnitude of velocity a little on the higher side, requires for the magnitude of μ_m and thus, also of C_i, an exceptionally high value, which is beyond the reach of any oscillation or structural frequency.

The excitation relaxation mechanism, therefore, cannot be considered as a suitable hypothesis to explain the observed facts in liquids, although attempts are still being made by some workers to utilise this process for the explanation of the anomalies in some of the liquids.

4. SECOND VISCOSITY COEFFICIENT, FLOW AND ABSORPTION

Attention has also been diverted in other directions to understand the abnormal absorption in liquids. Noteworthy among these is the proposition of the Second coefficient of viscosity proposed by Eckart (1948), from a theoretical analysis of the hydrodynamical equation of motion. It attempts to explain the flow of the medium and the anomalous absorption, simultaneously, as necessarily related phenomenon. According to this hypothesis, it is considered that the general equation of motion in an elastic medium, in the process of its reduction to the Navier Stokes relation for the fluids, leaves out a term akin to bulk viscosity, which is considered not to be applicable to fluids. It is suggested that in the case of ordinary liquids this bulk viscosity or the second viscosity term should not be left out. As a result of this introduction of the second coefficient of viscosity, a second order effect is obtained by Eckart that would generate a flow of the liquid. It is further considered that the second coefficient of viscosity would be associated with an absorption of energy, in a way similar to the ordinary shear viscosity coefficient, and thus, would explain the anomalous behaviour regarding absorption in liquids. It was suggested that the velocity of flow would give us a measure of the ratio of the two viscosity coefficients, which may be compared with the ratio of absorptions due to Stokes theory and that due to the excess. Experiments were performed by Liebermann (1949) to determine the value of η'/η, for different liquids, from the measurement of flow, and it had been pointed out by Rosenhead (1954) that the ratio corresponds to the ratio of the anomalous and Stokes absorption in liquids, which tend to indicate that the anomalous absorption is caused by the second viscosity coefficient of the liquids.

Further theoretical works on this line have shown (Markham 1952, Nyborg 1953), that the same type of flow characteristics would be obtained for any other process of energy dissipation, besides dissipation due to second coefficient of viscosity, if there is any. The mechanism of flow, therefore, does not require the hypothetical second coefficient of viscosity. It may, therefore, be discarded unless it is considered to be the only possible alternative to explain the abnormal absorption in liquids.

It may also be noted here that Nyborg, in his well executed theoretical work, has shown that a flow can be generated only when there is superposition of waves. An elementary wave form would not obtain any associated flow. The flow is, therefore, not a consequence of any form of viscous absorption, which would apply to the elementary wave form also. A peculiar type of dissipation, under particular conditions of superposition, would be necessary to give rise to flow.

The characteristics of the flow, thus, require to be more throughly and critically studied, experimentally, before it can be utilised to give us any clue in the complicated problem of the propagation of elastic waves in liquids. Discussing on the likelihood of a variable proportion of accousting streaming to radiation pressure, Nyborg had aptly concluded that 'the sound field in liquids is characterised by a complicated pattern, difficult to specify'.

5. NECESSITY OF ATTACK AT MOLECULAR LEVEL

A different suggestion to explain and understand the propagation mechanism in liquids was made by Dutta and Mukherjee (1952), on the basis of a critical study of the spectral lines, obtained with the help of the sound field grating, in accordance with the Debye and Sears (1932) procedure. It has been repeatedly observed that the spectral lines by the ultrasonic waves passing through water is much sharper than that through Benzene. The spectral lines through Carbondisulphide was mcuh too broad and diffuse. That the diffuseness in Carbon-di-sulphade is not caused by the large attenuation was confirmed by taking the spectra through a wave grating in highly viscous Castor oil, which has almost as high an absorption coefficient as Carbon-di-sulphide and obtains quite sharp spectral lines. This absorption in Castor oil was, however, in accordance with the Stokes theory of absorption. It appears that the greater the anomaly from the Stoke's viscous absorption value, the larger is the diffuseness of the spectral lines obtained with the same generating source. The differences seem to be caused by an association of a group of waves, whose spread is a characteristic of the molecule.

From the above consideration, as well as from the consideration that, except for their two dimensional and three dimensional molecular structure no large differences in the physical characteristics of Benzene, Toluene and Xylene have been known, so as to produce a large divergence in the observed absorption coefficients, it has been considered that the problem of anomalous absorption can be understood only when one attacks the problem from the basis of molecular or rather intermolecular force constants and their probable range of variations. The extra large absorption coefficient of Carbon-di-sulphide, with no marked difference in the other physical characters from any other nonviscous organic liquid, except in the still simpler molecular configuration of a linear type, also points towards the same conclusion. The longchain viscous organic liquids, with little chance of variability of the intermolecular force constants, should obtain on these considerations, negligible change of the observed absorption from the calculated values on Stokes theory. This is in accordance with observed facts. A similar expectation is also satisfied in the case of the completely symmetrical, three dimensional molecule of mercury. A theoretical relation on these considerations was, therefore, suggested and worked out by Dutta (1952), from an analogy with the optical dispersion relation. It gives the propagation of a group of waves, whose spread is a characteristic of the intermolecular force constants. The conclusions seem to be promising enough, particularly in view of the other experimental results that have since been obtained. As there had been no other direct evidence about the existence of a non-homogeneous group of waves in liquids and also because of the theoretical difficulties in considering the propagation of such a group of waves, generated by a monochromatic source, the idea has not gained much ground. It may, however, be pointed out that the theoretical difficulty about the propagation of a group of nonhomogeneous waves, in a medium, appears to be gradually removed on considerations of the nonlinear oscillatory motion.

The problem of the anomalous absorption of elastic waves was, thus, in a melting pot and further experimental clarifications became necessary on the nature and process of dissipation of energy in the liquids.

6. ABSORPTION FROM MEASUREMENT OF HEAT GENERATED BY ULTRASONIC WAVES

Measurements on absorption of ultrasonic waves in liquids have generally been determined initially, with radiometers or with a hotwire detector of velocity amplitude. Later on, it has been determined more commonly by the intensity measurements on light diffraction spectra or from the attenuation of the initial and reflected electrical pulses of a generator, as observed on a suitable oscilloscope. Total heat measurements corresponding to all the incident energy passing through a thin window, in an otherwise closed thermostatic vessel, placed at different distances from the generator, have also been utilised by some workers (Parthasarathy, 1953), to get a measure of the absorption coefficients. There is a general sort of agreement in the results obtained by different workers, working with these different procedures.

Absorption coefficient, determined by the measurement of steady heat energy developed by the waves, in a limited liquid path, obtains values which give a completely different picture (Dutta and Samal 1954, 1957). In view of the peculiarities of the results, the experimental arrangement may be noted with advantage. Measurements of heat were recorded in thermostatic trap vessels of different sizes, filled up with the experimental liquids. These vessels were fitted with inlet and outlet windows to allow the beam of waves to pass through. The trap vessel could be placed at different positions, in an outer liquid, in which the ultrasonic beam was generated. The difference of steady temperature between the water bath and the outer vessel as well as between the outer vessel and the trap vessel gives one a measure of heat energy generated in the outer vessel or in the trap vessel, from a comparison with electric generators. The absorption coefficient of the outer liquid could be obtained from the measured heat energies in the trap vessel at different positions. Comparative absorption coefficients in different liquids could be obtained from the heat measurements in a trap vessel at a particular position, when it is filled with these liquids successively. When, however, one takes the measure of the heat generated in the outer vessel and also knows the fraction proceeding forward, one can calculate the energy incident on the trap vessel. The value of the absorption coefficient of the liquid in the trap vessel can now be calculated from the incident energy and the energy in the trap vessel.

Working with a 100 watt, 3 megacycle generator, it has been observed (Dutta and Samal, 1958) from measurements by the displacement of the trap vessel that the absorption coefficients in liquids like Xylene or Kerosine, whose α/ν^2 values, determined by other methods are of the order of 100×10^{-17} and 200×10^{-17} C.G.S. units, decrease comparatively steeply from a much higher value of about 3 or 4 times the known value, nearer the quartz, and more gradually at a larger distance, to a value which is of the same order, but somewhat larger than that obtained by other methods. Such high absorption in the nearer regions of the quartz has also been noted by other workers (Fay 1931). It has been considered by them that the wave form contains overtones in the vicinity of the quartz, which become wiped out more strongly, giving an ultimate steady absorption coefficient at a comparatively larger distance of about 10 cm. from the quartz.

It has also been observed that the comparative values of absorption in Carbon-di-sulphide and Xylene, as obtained from measurements in small trap vessels at a particular position are in the ratio of only about 2 to 1, as against the measured ratio of about 50 to 1 by other methods. When, however, one calculates the amount of incident energy as described above, and calculates the absorption coefficient in Xylene or Kerosine, from the heat energy developed in a trap vessel of 1 cm path, one obtains an excessively high value of α/ν^2, as about 2000×10^{-17} units, in place of the low value of about 100 to 200×10^{-17} derived by other methods. Measurements in longer trap vessels, reaching upto 15 cms in length, obtain a rapid drop in the calculated value of absorption coefficient towards its known value. It indicates that there is a large dissipation of energy immediately behind the partition. These are very curious findings and make the problem of anomalous absorption more complicated and unexplainable. To eliminate the possibility of having this peculiar effect on account of the thin mica window as also of any probable electrical effect on the metallic core of the trap vessel, partitions of thin paper and cellophane and trap vessels made completely of Plaster of Paris had also been tried with the same effect.

It was necessary, thus, to study the role of the partitions in the path of the beam more critically. For this purpose the trap vessel had been placed at about 15 cm. from the quartz (Dutta, Subudhi and Samal 1958) and one or two partitions of the same dimension as the trap window had been placed in front of the vessel and at different positions. The trap vessel, without any other obstruction, obtains a steady temperature difference corresponding to about one tenth of the energy proceeding forward from the quartz, when the outer liquid and that in the trap vessel were both kerosine. An extra partition at 2 cm. or 12 cm. from the quartz or two partitions at 2 and 12 cms. from the quartz reduced the steady energy in the trap vessel by about 15%, 40% and 80% respectively. Any form of scattering or reflection of the waves would have reduced the measured energy by a larger amount, with a partition nearer the quartz, as against the observed facts. The reduction of the intensity by two partitions is, also, not accounted for by the reduction in intensity due to individual partitions. Thus, instead of clarifying the subject of investigation, this study by extra partitions had made the problem still more confused.

7. RADIATION PRESSURE AND FLOW MEASUREMENTS WITH PARTITIONS

It became necessary, thus, to have a measure of the progress of the wave energy behind each partition individually, so that one might get the explanation of this complicated process. For this purpose the deflections of an air-gap double cellophane disc as also of a single cellophane disc, suspended by unspun silk threads from a rod above, and placed in the path of the beam, have been measured with a travelling microscope (Dutta, Subudhi and Samal 1958). These deflections would measure respectively the total energy due to radiation pressure and flow and the unassociated flow, with due consideration of the small area covered by the metallic ring. Lateral and longitudinal movements of the suspending rod enabled one to place the discs at any desired positions, the disc not in use being kept out of the path of the beam.

The procedure of the experimental set up had been tested by measurement of the absorption coefficient of some liquids like Benzene, whose α/ν^2 values are known from other procedures. Good agreement between the values obtained by this procedure and the previously known values vouchsafe the suitability of the set up for further work on measurements of intensity and absorption. It had been observed that the absorption coefficient of kerosene, whose value is not known from provious works, obtains α/ν^2 as 250×10^{-17} in the free condition at larger distances. The absorption coefficient as determined from the deflection measurements at two nearer positions obtain α/ν^2 as about 1000×10^{-17}, at regions near the quartz and also immediately behind a thin mica partition. The value comes down to nearly normal value when measurements are taken at a larger distance from the mica, placed close to the quartz. These measurements immediately explain the large magnitude of the absorption coefficient obtained previously in smaller trap vessels as also the drop in the value with the larger vessels. Large absorption coefficient in regions near the quartz also confirms the previous values by the heat measurement procedure.

The most illuminating finding in this procedure has been obtained with a number of partitions. It has been noted that when one places more partitions in front of the measuring disc, suspended in kerosene, the total intensity, as obtained from the deflections of the double cellophane disc, decreases strongly at first and then more gradually, such that with three partitions in front of the disc, placed at any position, the intensity comes to a steady value which is unaffected by four partitions. The amount of the constant transmitted energy through three or four partitions comes to about 50%, of the unobstructed energy. When one replaces kerosene by strongly absorbing Benzene, a similar effect of a nearly steady value of deflection with either three or four partitions has been observed. The transmitted energy is, however, reduced to nearly 30% of the unobstructed intensity, which is appreciably smaller than the recorded observations with kerosene.

8. COMPOSITE CHARACTER OF WAVES

This is a very curious and instructive finding, which states that the propagating wave system is composed of groups of easily dissipated and nondissipating types. The easily dissipatable group is eliminated by stages and must, therefore, cover up a range in the propagating system. The unaffected constant group is expected to be of homogeneous character. One, therefore, obtains from the experimental results that the strongly absorbing Benzene is associated with a larger percentage of nonhomogeneous group of waves, which are easily dissipated. This indicates that the production of the associated nonhomogeneous group of waves, is a character of the liquid.

The production of the nonhomogeneous group of waves by the liquids is further corroborated by the experimental results with a double system of partitions in kerosene. When the first system of four partitions, placed near the quartz, have transmitted only the nondissipating constant part of the wave system, a second system of partitions, at a larger distance, again behaves in the same fashion as before, reducing the measured energy on the disc by stages. This indicates that the nonhomogeneity has again been produced by transmission through the liquid.

These observations are in close conformity with the previous experimental finding on the width of the spectral lines and the theoretical duductions from intermolecular force considerations, noted previously. It may be further, pointed out here, that with higher frequencies, one gets a much larger percentage of decrease by the interposition of mica partitions. It tells us that the associated nonhomogeneous group increases with frequency causing the well known phenomenon of larger dissipation with higher frequency. The finding of Richardson (1934) that in Carbon-di-oxide and nitrous oxide gases the beam of ultrasonic waves appear to be in a much more diffuse condition than in oxygen gas, such that a smooth and a rough reflector does not impress any change on the beam through Carbon-di-oxide and Nitrous oxide, might also have been caused by a comparatively larger percentage of nonhomogeneity as compared to that through oxygen.

We are also in a position now to understand the experimental results on heat measurements in a trap vessel, with or without one or two partitions. The trap vessel with two extra partitions are equivalent to four partitions, placed in the respective places. As the energy transmitted by three or four closely placed partitions are the same, it would have left no energy to be recorded in the trap vessel with two close partitions before it. When the partitions are separated by a large distance, a fair amount of the nonhomogeneity reduced by the first partition, would again be developed by the passage through the liquid. The third and the fourth partition would now behave as the second and the third partition and would give us some energy trapped between them, which may be considered to be equivalent to the box. Such small values of energy have been recorded in the experimental set up discussed before. The effect of a single partition close to the box or away from the box is also understandable on similar reasoning.

The nature of composition of the nonhomogeneous group could be obtained from a study of the diffraction spectra, produced by the wave field. It has been shown by Sanders (1936) and also by Samal (1958), that the number of spectral lines observed, is a measure of the intensity of the wave energy. The spectral lines could naturally, be generated by a homogeneous group or by a nearly homogeneous group only. Presence or absence of a harmonic group of waves would give rise to the appearance or disappearance of some higher order spectral lines without affecting the lines due to the fundamental wave. Experimental study of spectral lines, when the light beam passes through the sound wave grating in a near region of the quartz, which is either unobstructed or transmitted through three micas, has led, on the basis of the above reasoning, to the inevitable conclusion that the complete system composing the beam is a nearly homogeneous group of waves, and no harmonics appear to be associated.

9. ORIGIN OF FLOW OF THE MEDIUM

Lastly, one could make some significant remarks on the nature and origin of the flow of the medium, as derived from these experimental studies. It has been observed that the percentage of flow intensity, in relation to the vibrational energy as measured from the deflection of the single cellophane disc and the difference in deflection of double cellophane and single cellophane discs, varies with the condition of the experiment. It may be pointed out that a proper measure of the flow energy or rather of the generated energy of the flow type, can be obtained only by measurements behind a partition, so that the cumulative effect of the flow does not vitiate the measurements. The observed results of a strongly decreasing percentage of flow energy with increased number of partitions indicate that the flow energy is caused by the nonhomogeneous group of waves. Indeed, about 50% of residual vibratory energy after three mica partitions obtains almost negligible amount of the associated flow energy, whereas about 75% of the energy passing through the 1st mica partition has about 30% of the associated flow energy. Further corroborative evidence is obtained from the observations that the percentage of flow energy behind a mica is much stronger in Benzene as compared to that in kerosene and also for higher frequencies in comparison to that of the lower frequencies. In view of the already discussed composition of the wave system in Benzene and for higher frequencies of oscillation, the association of the flow with the nonhomogeneous group of waves is very clear. As already pointed out before, Nyborg, in his theoretical consideration on the generation of the flow energy had come to a similar requirement of the wave characteristics. The unknow complicated pattern of the sound field, about which Nyborg had made observations, as a conclusion, appears to be gradually resolved by the aforesaid study.

10. CONCLUSION

We conclude, therefore, that the elastic vibration in a liquid produces a group of nonhomogeneous waves, varying slightly from the main group of homogeneous waves, which become gradually absorbed on further divergence, through the mechanism of generation of the flow of the medium. The abnormal absorption in liquids may be considered to be produced by this mechanism. The nonhomogeneous group, so produced, is a characteristic of the liquid, depending upon the variable character of the intermolecular forces obtaining in such a liquid. It is further considered that the flow of the medium, caused by the existence of this nonhomogeneous group of waves, gives us a measure of the percentage of nonhomogeneous group associated with the homogeneous group.

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SECTION OF CHEMISTRY

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FROM SIMPLE MOLECULES TO HIGH POLYMERS

INTRODUCTION

The story of growth of a high polymer molecule,—how a tiny molecule being 'triggered' to activity goes on growing to a giant one, until it loses the original impetus to grow,—has its close parallel in the drama of life itself, where a simple nucleus gets blessed to a minute speck of life and grows under favourable circumstances to an organic whole. The daring, ingenious net of imagination of polymer chemists has probed deep enough into this restless whirl of molecular activity for the last quarter of a century or so, so as to reveal to us a fairly clear picture of this seething, tempestuous growth on a molecular scale. Nature has lent an added charm to this study of polymer growth, as her own domain teems with such activity of luxuriant diversity and complexity. The growth of the giant molecules of cellulose in the vegetable kingdom, or of proteins and nucleic acids in the animal kingdom are examples to the point, and it is a revealing commentary to the inadequacy and impotency of our otherwise powerful methods of scientific exploration in this field that we yet know little of the neat, simple and unerring method by which she performs these marvels of chemical synthesis.

Despite these deficiencies polymer science in a surprisingly short time has attained a scientific maturity, such that events can now be pursued and decisions can be taken with more footing of reasoned anticipation than of wild chance. The term, 'tailor-made' plastics illustrates a facet of this status of scientific manhood to the laity. Another measure of the virility of polymer science to the common man is probably the colossal contribution already made by polymers and polymerization to human comfort and progress of civilization. But the power and beauty of the science of high polymers lie not so much in what it has materially achieved but in what it suggests and promises to look into. Our recent spectacular advances in the knowledge of all polymers related to life process and our very recent success in producing stereospecific polymers are bound to bring an increasing understanding, control and command over the biology of life. The viruses, which are regarded as the twilight zone between the living and the nonliving, and have been recently crystallised, broken apart and resynthesised to life, are likely to yield the secret of their life force in the near future under insistent enquiry in the polymer chemists' test tube. And, from then on, the day may not be far when the science of high polymers, in its widest sense, shall launch itself into the supremely exciting adventure of creation of life itself. Whether an unbridgable gulf remains between the living and the non-living, whether the unknown creative force which ushers life into existence is amenable to be completely understood and mastered, whether the theory of an omnipotent supreme creator would be irrevocably knocked down from its present pre-eminent position, are delicately balanced questions at present. But the potentiality of polymer science, in its widest sense again, to venture into the hallowed citadel of creation of life, which has so far been held to be the monopoly of an unknown creative force, marks it the supremely exciting and worth all human creative effort.

From these introductory remarks it is clear that to sketch the biography of a high polymer molecule, our avowed task according to the title of the present lecture, would be an exciting job by itself, but considering the inherent limitations necessarily imposed by the settings of the present lecture, we shall confine ourselves here to the much more modest task of discussing just a few selected chapters in the life history of a polymer molecule, particularly the results of some recent researches which seem to us specially suggestive and important in these fields. Naturally, personal bias, inclination and interest have played no mean role in this selection, and so my presentation is more a reflection of my personal interest than any relative merit of subject matter or workers.

May I now take leave of you to conclude these introductory remarks by expressing my sincere thanks to the fellow chemists of our country who have afforded me this opportunity to deliver this lecture under the auspices of the Indian Science Congress Association.

Some Important Events in the Classical Period of Polymerization

Emil Fischer of Germany has been rightly called the spiritual father of modern high polymer chemistry by Hermann Mark, for his planned synthesis of polypeptides in 1914. Though an eighteen-member polypeptide was as far as he could go, still that it is an achievement of no mean order can be judged from the fact that only three years back (1955) du Vigneau was awarded the Nobel prize in Chemistry for synthesising in the right stereospecific form only an eight-membered polypeptide, oxytocin, which is biologically active even in microgram quantities, and that the latest award (1958) of the same honour has been made to the British Chemist, Sanger for unravelling the mystery of the giant insulin molecule containing as many as 777 atoms. Two other Nobel Prize winners in the field of high polymers in very recent years are Staudinger of Germany in 1953 for his pioneering work in high polymer chemistry and Sir Alexander Todd of Cambridge in 1957 for his elucidation of the structure of nucleic acids.

Long before Emil Fischer, however, it is nearly a century that small molecules had begun to be converted to very large ones by two groups of workers ; one group with the conscientious objective of producing high polymers, and the other group coming upon the polymers by chance incidental to an altogether different pursuit.

Another outstanding work of this period almost synchronising with that of Emil Fischer's polypeptide synthesis, is the technical production of butadiene and its polymerization to synthetic rubber by Lebedev of Russia, a work for which Lebedev has received high national recognition in the form of laboratories and institutes being dedicated to his name. It was with great pleasure that I had the opportunity to visit these places last year as a member of a scientific delegation led by Prof. M. S. Thacker, but greater still was my pleasure to find the respect, almost verging on awed reverence, in which Lebedev is held by the polymer scientists of the U.S.S.R. and the pride they take in this discovery by one of their own people.

In the industrial front many technically important high polymers, i.e. plastics, resins, rubbers and fibres, to name a few, Bakelite, the ureas, melamins, the alkyds, the epoxy resins, with the polystyrenes, the polymethyl methacrylates, etc., meanwhile started their career. Inspite of these brilliant technical achievements, the fundamental picture continued to remain confused for some time right almost into the early thirties. The new science of colloid chemistry with an uncritical impatience and immature zeal, to bring every unusual phenomena in its fold, stamped all polymers as colloids, presumably, association colloids, which being the fashion of the day somehow appealed to most workers and brought confusion in its wake. We owe it to the genius of Staudinger who clearly perceived polymers as covalent compounds of high molecular weight and unrelentingly fought issues to strip off the last vestige of colloidal mooring from high polymer chemistry, and launched it on its own steam on the high road of classical chemistry. The X-ray studies of Meyer and Mark on natural polymers also contributed in no uncertain measure to the downfall of the association colloid hypothesis. Thus, when the late lamented Carothers in the U.S.A. started his brilliant researches in early thirties, which culminated in nylons and paved the way for many others, the road was open to proceed on the firm foundation of structural organic chemistry.

Naturally enough, such assemblies of large molecules with a bewildering diversity of size, shape and mechanism of formation, have offered a very fruitful field of application of the science of statistics. It was easily realised that even the shape of a macromolecule with free rotation at each carbon-carbon bond has only a statistical significance, and Kuhn of Germany and also Mark and later on, Flory of U.S.A. have made very fruitful applications of statistics to the interpretation of the properties of high polymers.

THE PROCESS OF POLYMERIZATION

Barring some border line cases, the process of polymerization, the knitting together of simple molecules to giant ones, takes place by two fairly distinct mechanisms, called polycondensation and addition polymerization respectively. Typical linear polycondensates are, nylon (a polyamide) and 'terylene' (a polyester), and typical linear addition polymers are polystyrene and polyvinyl chloride—acetate copolymer (P.V.C. of commerce)

We need not go here into the technicalities of this distinction but suffices it to say, that we shall treat polycondensation separately from addition polymerization and for brevity, where no confusion can arise, we shall call addition polymerization, simply polymerization. It may be added, however, that there are borderline cases which bring about a little blurring of the above sharp distinction. This may well be just one more example of the ultimate fallibility of man's coarse high-handed attempt towards a sharp physical classification of Nature's subtle phenomena.

POLYCONDENSATION

The commercially important polycondensates like Bakelites, ureas, melamins, alkyds, maleics, etc., and the more recent ones like nylons (polyamides), terylenes (polyesters), epoxy resins, etc., though they represent huge business propositions, offer comparatively little difficulty in the theoretical understanding of their mechanism of formation. They are well treated theoretically from three aspects, viz., the kinetics of polycondensation, the gelation of three-dimensional polymers and the molecular weight distribution. On the assumptions that polycondensation is a stepwise reaction and the intrinsic chemical reactivity of a given functional group is independent of the molecular size, all the above three aspects have been satisfactorily dealt with. In fact, the agreement between theory and experiment is so close, that there is hardly any fundamentally interesting activity beyond routine investigations and matter of details in this field for a considerable number of years.

To me, the development in 1946 of the linear polycondensate of terephthalic acid and glycol, the 'terylene' or 'dacron' of commerce, demonstrates once again, that a truly scientific mind has to transcend the slavish bondage of set theories and preconceived notions to venture into new heights in science. No respectable chemists before Whinfield and Dickson, the discoverers of terylene, would conceive of a polyester fibre for textile use as it would hardly have a chance to withstand the laundering alkali, but now we know how in terylene, the benzene rings effectively shield the ester group against attack by alkali. This polymer has been lately developed by the firms of Du Pont under the trade name 'mylar' in the form of films. A few months back when I was invited to deliver lectures in the same laboratories of Du Pont which developed this film, I was shown some of the remarkable properties of this film. Gold and silver can be vacuum-deposited on this mylar film without affecting its transparency, and many decorative effects on textiles and upholstery now common in the U.S.A. and also 'on view' on our recently U.S.A.—returned young people, are owing to such treated mylar films.

Interesting work in polycondensates has emanated lately from some laboratories in India. Mitra of Delhi has very recently opened up a new avenue of investigation for many polycondensates by his finding that an insoluble polycondensate containing acid or basic groups can be titrated in suspension to yield various information including faults (löcherstellen) in its three dimensional structure and sometimes its D.P. The technique seems to be a little tricky as it has not been possible so far to have this apparently extremely valuable method to be adopted in other laboratories. Yeddanapalli of Madras has lately re-investigated the alkalicatalysed phenol—formaldehyde polycondensation and the polymerisation of Δ-3-carene. Mukherjee of Kanpur as also Subba Rao of Bombay have developed Bakelite type mouldings from molasses and oil seed cake respectively, and Choudhury of Calcutta has done similar things from other agricultural waste materials. They certainly deserve all encouragement towards development to commercial exploitation stage.

ADDITION POLYMERIZATION

As a great deal of precise information began to be collected in the thirties, it became clear that vinyl polymerization is a chain reaction. Since chain reactions were already well-known to occur in a variety of chemical change, e.g. oxidation, halogenation, decomposition, etc., and their characteristics fairly well studied, it was but a simple step to extend the fundamental theory to such polymerization. So, polymerization comprises the usual three steps of chain mechanism :

(i) Initiation : $M \longrightarrow M^*$

(ii) Propagation : $M_n^* + M \longrightarrow M_{n+1}^*$

(iii) Termination : $M_m^* + M_n^* \longrightarrow M_{m+n}$ or $M_m + M_n$

The initiation may be thermal, photochemical, free radical or ionic. The substituted ethylenes which easily polymerise always have, excepting some fluoro-olefines, a methylene group, i.e. their formulae are of the type $CH_2=CHR$ or $CH_2=CR_1R_2$ and if the substituents are electrophilic they are more easily polymerized by a free radical or anionic mechanism than by a cationic mechanism, and the reverse seems to be true for nucleophilic substituents. These elementary facts of polymerization have however, yet to be satisfactorily explained.

Researches on addition polymerization in our country have been mostly limited to kinetics of polymerization by Kapur and his collaborators in N.C.L., Poona, by Misra, Chadha and others in Lucknow University, by Santhappa and co-workers in Madras University, by Muthana in I.I.T., Kharagpur and by at least three groups of workers in Calcutta, Sadhan Basu and also Chowdhury in Calcutta University, and ourselves as also Sinha in Jadavpur. Notable very recent researches outside the field of kinetics are the study of spreading properties of macromolecules on water by Gururaja Doss of Kanpur (now of Karaikudi), physical chemistry of polyelectrolytes including their chromatic interaction with dyes by Sadhan Basu, and theoretical researches on viscosity of polymer solutions by Bhatnagar, Biswas and Gharpure of N.C.L. Sadhan Basu's very recent quantum mechanical calculation by localisation approximation of the energetics of the propagation reaction is another worthwhile theoretical contribution.

INITIATION

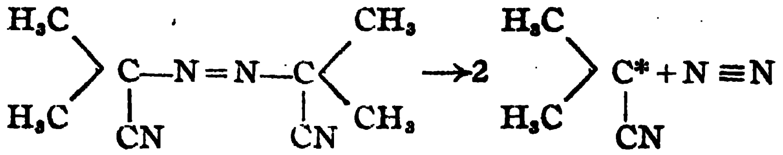
Uncatalysed thermal initiation (as also photo-initiation) has offered utmost difficulty to experimentalists as also to theorists, because of a lack of reproducibility of experimental data, and lack of a suitable theoretically satisfactory initiation process.

A number of substances capable of generating free radicals have been found to be powerful initiators for vinyl polymerization, benzoyl peroxide and azobisisobutyronitrile being the ones much used. If the free radical is highly stabilised by resonance, naturally it would be reluctant to initiate polymerization. Thus the classically stable triphenylmethyl radical is found not to initiate polymerization of vinyl or allyl acetate. Generation of free radicals at a convenient working temperature requires the existence of an energetically feasible mechanism. The benzoyl peroxide undergoes O-O bond rupture with an energy of activation of nearly 30 Keal to two C_6H_5COO radicals, which later decompose to phenyl radicals and carbon dioxide. Either of these radicals initiate polymerization.

$C_6H_5—CO—O$ $\qquad$ $C_6H_5—COO^* \longrightarrow C_6H_5^* + CO_2$

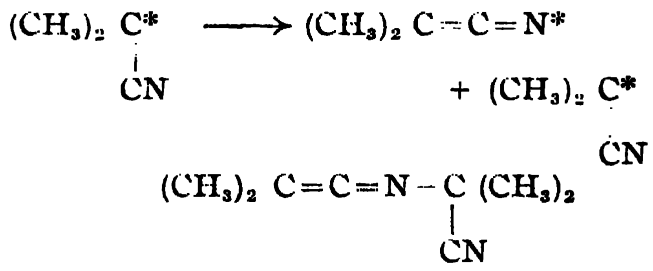
$C_6H_5—CO—O$ $\qquad$ $C_6H_5—COO^*$

Azobisisobutyronitrile like many other substituted azoalkanes decomposes by the concerted rupture of two C-N bonds, the high energy required being compensated partly by the accompanying establishment of a N$\equiv$N triple bond.



Bartlett of Harvard and Hammond of Caltech, California have worked out detailed mechanism of many other generators of free radicals.

Of current interest is the 'Cage effect' i.e. the preferred reaction of the radical pair formed in the solvent cage before they diffuse out. The occurence of cage effect can be seen from the fact that the two free radicals formed in the above reaction have the chance to recombine not only to form the parent compound but also a ketene—imine and very lately Bywater of Ottawa, Canada has demonstrated the formation of the latter:



$$\underset{\text{CN}}{(CH_3)_2\,C^*} \longrightarrow (CH_3)_2\,C=C=N^* + \underset{\text{CN}}{(CH_3)_2\,C^*}$$

$$(CH_3)_2\,C=C=N-\underset{\text{CN}}{C}\,(CH_3)_2$$

As regards initiation of polymerization by free radicals the fundamental step is essentially represented by the following equation,

$$R^* + CH_2=CHX \longrightarrow RCH_2\text{—}CHX^*$$

The initiating free radical if properly labelled has been demonstrated by many workers under varied conditions to be present in the polymer chain to the extent of 1 to 2 per polymer molecule, the precise number per chain being somewhat hazy owing to uncertainties inherent in determining average degree of polymerization.

If the termination rate is bimolecular (i.e. mutual termination of growing free radicals) it can be easily shown that the total polymerization rate should be nearly proportional to the square root of initiator concentration. The above anticipation from theory has been abundantly verified experimentally by many workers. Chada and Misra have lately struck a discordant note by showing that at higher initiator concentration using six peroxides, and vinyl acetate, the rate of polymerization is much higher than that given by the square root relation and they rightly conclude that peroxides as initiators introduce complications not envisaged in our scheme.

Lately, much study has been made to determine the efficiency of utilisation of the free radicals formed by the decomposition of the initiator. The efficiency is generally found to be between 60 to 100 per cent showing once again that the essential framework of the theory is correct. Of the methods of determining efficiency, viz., direct counting of end group, from degree of polymerization and rate, etc., the method of using a scavenger molecule is of great interest and currently in extensive use. One such scavenger is the stable free radical, DPPH (2, 2-diphenyl-1-picryl hydrazyl) each molecule of which can consume one free radical. So, the rate at which this scavenger disappears from a system, as can be easily determined from the disappearance of its colour, is the rate of formation of free radicals, i.e. the rate of initiation of polymerization.

PROPAGATION

The propagation step, viz., the growth of the active centre has been investigated under intermittent illumination by the rotating sector technique to get the absolute values of the propagation rate, *kp*. For common monomers, the frequency factor is about 10^{6} and the energy of activation is nearabout 5 Kcal. Such low frequency factor is expected from the transition state theory assuming propagation to be essentially a bimolecular association process.

The basic thermodynamics is rather simple. The monomers polymerise under conditions, such that, the free energy decreases. This is contributed mainly by the fact that ΔH is negative i.e. polymerization is exothermic. Some typical values in Kcal at near 76°C are styrene, 16·1, methyl methacrylate, 13·0, vinyl acetate, 21·3 and acrylo-nitrile 17·3. Since a polymer is more ordered than a loose assembly of monomers as can be easily realised by considering that a monomer molecule is capable like any ordinary molecule of having unhampered all the usual degrees of freedom including free translation and external rotation, whereas the monomeric segment of a polymer has lost all these degrees of freedom and have gained only some relatively inefficient vibrational and two internal rotational degrees of freedom, polymerization brings about a decrease in entropy. Thus the entropy and enthalpy in the free energy equation, $\Delta F = \Delta H - T\Delta S$ act in opposite directions, a reflection of the primordial conflict between energy and entropy, order and disorder (Hinshelwood), and it may happen that at certain temperature one overtakes the other. At nearabout such temperature, the polymer would become thermodynamically less stable than the monomer and depolymerization would set in. Such temperature is called "ceiling temperature" above which depropagation and depolymerization set in by a mechanism opposite to that of propagation. From equilibrium studies near ceiling temperature, heat and entropy of polymerization can be determined, and the latest values as determined by Bywater of Canada for methyl methacrylate and methacrylonitrile are around—15 Kcal for ΔH and—30 e.u. for the entropy change. The same phenomenon is clearly discernable in copolymers of SO_2 and olefines as reported by Dainton of Leeds University, as the ceiling temperature for many lies in a very convenient range, e.g. between room temperature and 100°C. Incidentally, these types of copolymers, say from SO_2 and Cetene—1 are examples of a very unusual type of copolymers, derived from two monomers, none of which can polymerize independently.

TERMINATION STEP IN POLYMERIZATION

In ionic polymerization the termination step is evidently unimolecular involving the expulsion of the charge on the growing end of the polymer but reliable data are sparse. In free radical polymerization it is necessarily bimolecular where there is a square root dependence of the rate on the catalyst concentration. The frequency factor is nearabout 10^{8}

and the energy of activation is almost zero (2 to 5 Kcal). The question which is widely debated currently is whether the termination occurs by disproportionation (a) or by combination (b)

$$M_m^* + M_n^* = M_m + M_n \quad \ldots \quad \ldots \quad (a)$$

$$M_m^* + M_n^* = M_{m+n} \quad \ldots \quad \ldots \quad (b)$$

The experiments brought to bear on this problem are based on either some kind of end group analysis or determination of molecular weight distribution and the verdict is not yet final and unequivocal. It appears particularly from 'tracer' experiments that polystyrene formation at 60°C is exclusively by combination, whereas disproportionation occurs six times as frequently as combination in polymethyl methacrylate formation.

In contrast with initiation, propagation and transfer, the termination reaction involves two units both of which are high polymeric. Hence, it is conceivable that the two growing ends will have increasing difficulty to meet each other, if the viscosity of the system is increased. Hence, polymerization is often autocatalytic as the viscosity of the system increases with polymerization, or runs at a higher speed if the monomer is thickened at the outset by adding polymers, and this increase of speed, as the theory demands, is attended with an increase in molecular weight, a rather abnormal behaviour in polymerization. This is called, Trommsdorf effect, gel effect, 'peaking' or 'explosive' polymerization. The retardation of termination i.e. a decrease of termination constant, K_t which causes the above effect implies a longer average life and a higher concentration of free radicals. In the limit of a system of very high viscosity, say a gel or a solid, we should expect from an extension of the above concept to have large concentration of *trapped free radicals* of long life. This has been realised and we shall discuss it in another section.

CHAIN TRANSFER

A growing free radical, instead of growing, occasionally reacts with a molecule in its vicinity generating a 'dead' polymer molecule and a new free radical capable of functioning as a new active centre for polymer growth. This will leave unaffected the rate of polymerization and the kinetic

M_n^*	+	(say) CCl_4	——	M_nCl	+	CCl_3^*
Growing Free Radical		Solvent		'Dead' Polymer		A new free radical

chain length, but will lower the molecular weight. Much valuable experimental work has been done by Indian workers in this field and in fact, since the earliest work by Basu, et al the major activity in this field has been shared between the Calcutta, Lucknow, Madras and Poona schools, the last three under the leadership of Misra, Santhappa and Kapur respectively. No doubt the fact that extremely valuable data can be produced in this field with very simple equipment only at the cost of much painstaking labour, a condition easily available with the highly intelligent and energetic workers in our mostly ill-equipped laboratories, has made us all lean rather heavily towards this field. Detailed theoretical calculation of the distribution function from our laboratory by Majumdar, and by Watson in England has shown that the form of the distribution function remains unchanged by chain transfer and experimental verification has been obtained for the same.

Chain transfer constant, viz., the ratio of the transfer rate constant to the propagation rate constant is usually determined; and, a large volume of data, quite a few of them being none too reliable for lack of necessary extreme experimental precautions, has accumulated. Values for say, styrene are of the order of 10^{-5} for the more common solvents, i.e. a styrene free radical on the average does transfer reaction with a solvent once for every hundred thousand times it adds on monomer to grow. Chloroform, CCl_4, CBr_4, mercaptans, etc., are powerful chain transferring agents and that is why, they are used in industry as 'regulators' (of molecular weight).

The usual trend of values was thought to fit in the general pattern expected from the concept of resonance stabilisation of the transition complex. Thus, anionoid styrene and vinyl acetate radicals are strongly transferred by the electrophilic CCl_4 and thiols, and weakly by the electron-donor tertiary amines, whereas the reverse is more or less true for the cationoid acrylates and nitriles. Such naive explanations sufficed for the main framework at the beginning but as intractable facts are increasingly rebelling against such conformity, it seems that there has been gross oversimplification perhaps on an essentially correct framework and overemphasis of one or two factors in preference to other yet unrecognised ones.

Some recent observations are highly disturbing to the fundamental notion of chain transfer. It is evident from equation of chain transfer reaction that a fragment of the solvent should be incorporated in the polymer, and this had been experimentally verified in some cases. Recently, some workers using chlorobenzene and bromobenzene as the chain transferring agents have failed to detect any halogen in the polymer and have suggested that the solvent merely helps to transfer a hydrogen atom from one monomer to a growing radical.

$$M_n^* + \underset{\text{(Solvent)}}{S} \longrightarrow \underset{\text{Complex}}{[M_n^* \ldots S]} + M \longrightarrow M_n + S + M^*$$

More work would be needed to examine such a profoundly new mechanism.

Some Recent Developments in Polymer Formation

So far we have been discussing recent elaborations of the basic almost classical concepts of polymer growth, but lately some significant new grounds have been broken, and we shall make a brief sojourn over the salient regions of these new territories. We shall specifically touch upon the following aspects:—

(1) *Graft and Block Copolymers.*
(2) *'Living Polymers' of Szwarc.*
(3) *Synthesis of Protein analogues.*
(4) *Application of Radioelements.*
(5) *Trapped Free Radicals.*
(6) *Stereospecific polymers.*

Newer Copolymers

The theory of copolymerization is fairly well worked out as to the composition of the polymer chain and kinetics. Joshi and Kapur have suggested an alternative method of calculation of the monomer reactivity ratios and we have examined the degree of polymerization taking all possible types of chain transfer into account.

Interesting developments have however lately taken place in synthesising peculiar kinds of copolymers called block copolymers and graft copolymers. If A and B are monomer units the usual copolymer (-A-B-A-B-A-B-B-B-) is a random repetition of A and B under the overall restriction of the conditions of experiments. But it is possible to prepare long successions of A followed by a long succession of B i.e. a copolymer of the type—A-A-A-A-A- —B-B-B-B-B-B-. Such copolymers are called block copolymers.

A theoretically interesting method of making such copolymer is due to Melville of Birmingham (now Sir Harry Melville, Secretary, D.S.I.R., England). The method is to stream a monomer through a capillary into another monomer and initiate polymerization photochemically at some convenient point in the capillary. If the average life of the growing radical is less than the time required by it to reach the second monomer at the end of the capillary, the still growing radicals will grow at the expense of the second monomer and block copolymers will result. A more generally applicable method however is to chemically combine polymers with preformed functional end group. Thus, terylene has been linked with polyethylene oxide. The resulting block copolymer is found to be almost as crystalline as the terylene component but having better flexibility, moisture recovery and behaviour with dyes.

Another remarkable method of recent development is due to Watson of British Rubber Research Association. The method is extremely simple and consists in cold mastication under nitrogen of a rubber with a vinyl monomer, and lately, of two vinyl polymers. On mastication of rubber some covalent bonds are torn apart generating two free radical ends, and these ends grow at the expense of the monomers available in their vicinity. A large variety of block copolymers, some of very unusual composition, has been very recently prepared by this method.

Graft copolymers, as the name implies, are branched polymers in which the branches are of a different monomeric composition than that of the main backbone. One of the methods is to produce functional groups on a polymer chain and let it grow in another monomer. An illustration of this method due to Mark and his coworkers is to prepare isopropyl derivative of polystyrene, which is readily oxidised to hydroperoxide. This hydroperoxide is now allowed to initiate polymerization in another monomer, say methyl methacrylate and a graft copolymer containing methyl methacrylate branches on a polystyrene chain is readily obtained. Similar reactive centres capable of growth in a second monomer can be created by photolysis of suitable groups. Thus Norrish of Cambridge has used photodissociation of C-Br in bromoderivative of polyvinyl methyl ketone to initiate such grafting. Branches can also be formed in a random manner by chain transfer on a polymer. In fact conventional polyethylene, prepared at high pressure and high temperature, is a highly branched polymer owing to this cause, the infra-red showing about one methyl group per forty or so carbon atoms, and this is why it is much less crystalline and lower melting (about 20°C lower) than straight chain polyethylene (more correctly called polymethylene), obtained by low pressure Ziegler method or by polymerization of diazomethane.

These novel types of copolymers have unusual solubility characteristics and by grafting highly hydrophilic polymers on highly hydrophobic backbone or vice-versa it has been possible to obtain high polymers which make water and benzene mutually miscible. Commercially they are also attaining importance and such types of copolymers of rubber and methyl methacrylate with much superior flex-cracking, fatigue resistance and lighter colour, are already in the market.

Another method of preparing such copolymers with long range periodicities by using high energy radiation will be dealt with in a later section. But a very recent method of outstanding interest from mechanism standpoint, viz., the *'living polymers'* of Szwarc of Syracuse, New York deserves special mention. Szwarc treats a condensed ring hydrocarbon such as anthracene with metallic sodium in tetrahydrofuran solution with scrupulous exclusion of oxygen. A colour develops owing to an electron transfer reaction. Now, if a monomer is added, the active centres on the hydrocarbon molecules grow by the propagation reaction but as there is no termination reaction, each macromolecule retains one active centre at one end. These polymers are called, *"living polymers"*. So, by using varied monomers at each stage we can prepare block copolymers with long succession of similar units.

BIOPOLYMERS AND THEIR ANALOGUES

Recently great interest is being shown in the synthesis of analogues of proteins and polynucleotides. The synthesis is usually by orthodox chemical methods and also by enzymatic method. A very successful method of synthesising polyaminoacids from N-carboxy amino-acid anhydride, discovered by Leuchs of Germany in 1908 deserves special mention, as the method was used by Woodward of Harvard a few years back and is used extensively at present by at least three groups of workers, viz., the Harvard School headed by Paul Doty, the English school of Bamford and coworkers, and the Israel group under Katchalski. We shall not go into the preparative aspect here.

The remarkable thing about these polymers is that unlike other macromolecules they tend to assume the form of a helix rather than of a random coil. In a study of the kinetics of formation Paul Doty of Harvard has lately observed that the rate of formation abruptly increases as soon as the polyaminoacid attains a certain average molecular size and he has shown that this is owing to the transformation of the statistical coil to the helix form. Polyriboadenylic acid obtained by enzymatic synthesis also showed similar transition beyond a certain molecular weight but to a double stranded helical structure, the two strands being bridged by hydrogen bonds between complementary bases. In fact it is now known that proteins form simple helical structure, and the nucleic acids two-stranded helices and, as the brilliant work of Ramachandran of Madras has demonstrated, the collagens (the protein of leather) triple helical structure. So important have lately been these helical structures in understanding the properties of these polymers as also some stereospecific polymers, that Prof. Mark in his inaugural lecture in the latest international polymer symposium (1958) held in Nottingham told us in a lighter vein that all respectable polymer chemists willing to maintain their respectability would have to become geometers and master the geometry of the helix.

RADIOISOTOPES AND POLYMER CHEMISTRY

Bevington of Birmingham University among others has made extensive use of the labelled atoms particularly C^{14} and S^{35} to elucidate problems of high polymer chemistry. The result has been mostly complementary to kinetic studies. This technique has been mostly limited to the use of labelled initiation to count the number of initiator fragments per polymer chain. From such end group analysis it has been possible to measure the absolute rate and efficiency of initiation, the nature of the termination process (combination or disproportionation), the nature of chain transfer with a dead polymer, etc.

As an illustration we can cite the recent work on vinyl acetate showing that extensive self-branching takes place during its polymerization. The method was to dissolve labelled polyvinyl acetate in the same monomer and let the whole polymerize. From this it was possible to isolate material consisting of the original active polymer with inactive side chains grafted on it. It was found that that abstraction of hydrogen atom takes place rather easily from a polyvinyl acetate macromolecule making the polymer highly branched.

Another simple illustration of this technique is the finding that polystyrene prepared by benzoyl peroxide initiation is radioactive irrespective of the site of labelling in the peroxide, i.e. the benzene ring or the carbonyl carbon, which prove conclusively that both C_6H_5 COO* and C_6H_5* are initiators of polymerization.

TRAPPED FREE RADICALS

We have already pointed out in the section on termination that retardation of termination may lead in the limit to trapping of free radicals, i.e. production of free radicals of long life. This has been experimentally observed in heterogeneous polymerization, when the polymer separates as an insoluble phase occluding a comparatively large concentration of long life free radicals. The existence of such trapped free radicals can be proved by physical and chemical methods viz., by paramagnetic resonance, by utilising the precipitated polymer as initiator of fresh polymerization, by their ability to react with D.P.P.H., and so on.

Another ingenious method of trapping free radicals is to expose a monomer emulsion to high energy radiation. By stopping the irradiation after a short period it is possible to prepare an emulsion of long life free radicals each of which is trapped in a single suspended polymer particle. In such cases the free radicals are not mere fleeting entities of vanishingly low concentration, but can be handled, transported and stocked for future use like any ordinary chemical. Vinyl acetate is particularly suitable for such experiments and later addition of another monomer to its emulsion containing trapped free radical has been used for making block copolymer.

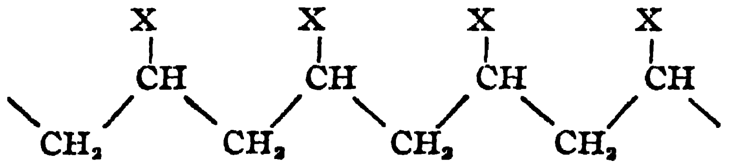
Solid blocks of polymers on similar irradiation under suitable condition can also house trapped polyradicals, obtained most likely by knocking out an electron from the C-C bond of the polymer chain or an atom or a group existing as pendant structure to the backbone of the polymer. If this sample of irradiated solid is later exposed to the vapour of a monomer, the chain would proliferate to form a graft copolymer. Fibres can be surface-treated by this method to improve their properties.

Such irradiation may also produce cross-linking or depolymerization depending on the condition. Polyethylene by exposure to high energy radiation has been so much improved in properties that polyethylene bottle so treated can be sterilized in steam.

STEREOSPECIFIC POLYMERS

A recent development of far-reaching importance and significance, perhaps the greatest since the inception of the science of high polymers, has taken place a few years back in 1955 or so. This is the stereospecific synthesis of high polymers by van Natta of Italy and by Zeigler originally of Germany and now of U.S.A. So momentous an onslaught on our frontier of knowledge this discovery has made that Prof. Tobolsky of Princeton has called it the greatest personal thrill of his chemical lifetime. In the Zurich meeting of the International Macromolecular commission in 1955 in which the news of this discovery was heard for the first time by myself and many others, the lobby talks and the proceedings were largely on this subject and in a vein as if a new planet had been discovered.

All natural high polymers have a unique spatial disposition of their constituent atomic groupings which has been the despair of synthetic organic chemists for over a century and is a glowing tribute to the consummate artistry, skill and economy of effort of mother nature in organization on a molecular level. Thus, rubber is practically all *cis*—1 :4 and a protein is all laevo. But synthetic polyisoprene molecule is a random mixture of cis and trans, and ordinary polystyrene, for example, is again a random mixture of dextro and laevo along the same chain. Due to this randomness in the spatial disposition of groups, the polymer chains cannot fit well in a crystal lattice and so, the crystallinity and consequently the mechanical properties are adversely affected. If the substituent group, let us call it X, be placed on the same side of the asymmetric carbon atom, i.e. all asymmetric carbon atoms are of either exclusively dextro



or laevo configuration, or alternatively one is dextro and the other is laevo, such chains can be easily fitted in a lattice as a result of its regular stereo-chemical pattern. The all-dextro or the all-laevo polymer is called *'isotactic'* and the regular alteration of dextro and laevo is called *'syndiotactic'* by van Natta, their discoverer.

All activity in this field may in a way be traced to the work of Zeigler, who in 1955 reported catalysts, obtained by the interaction of aluminium trialkyl and a titanium halide, which could polymerize ethylene at ordinary temperature and low pressure. This was hailed as a sensational technical achievement as the usual method of obtaining polyethylene of commerce employs a pressure of hundreds of atmospheres. Besides, the low-pressure polyethylene has much superior properties ; it has higher crystallinity and consequently, higher density and higher melting point, because of its comparative freedom from branching.

Van Natta at about the same time produced with the help of similar catalysts highly crystalline polypropylene, poly-α-butene and polystyrene which have since been followed up by the preparation of other highly oriented polymers. We can illustrate the superiority of isotactic polymer by the instance of polystyrene ; the polystyrene of commerce has a softening point near 80°C whereas samples of isotactic polystyrene have been produced with melting point above 200°C. Another interesting synthesis of oriented polymer is the recent synthesis of natural rubber, i.e. cis. 1-4 polyisoprene, with the help of heterogeneous catalysts. Intensive work is in progress in the field of Zeigler catalysts and isotactic polymers owing to its evident technical importance ; and, in Russia in every institute we visited which was in some way related to polymerization, we found brisk activity in this field including large scale trial by this technique. The mechanism of oriented polymerization on Ziegler-type catalysts is not yet clear but no doubt there is a directive effect on a molecular scale which reminds one of "Maxwell's demon" or a molecular template.

It has been surmised that some type of endless template or stencil-like arrangement on a molecular level exists in the living cell to mould out the stereospecific biological polymers which sustain life, and some have gone so far as to suggest that cancer is a damage of this biological mould such that it produces, though the right chemical structure, the wrong spatial configuration. Hence, any success in synthesising stereospecific polymers brings us, as it were, closer to an understanding and mastery of life itself. My only regret is that many of us in India are obliged to remain silent spectators of this epic drama though physically and mentally equipped to be earnest participants of it, due to the misfortune of being born in an underdeveloped economy in a period of acute national economic crisis.

SOME NOVEL POLYMERS

We like to take this opportunity to mention just a few interesting novel polymers whose development seems to be round the corner, on the basis of information received on a personal level during my recent trips outside our country. Polyvinyl fluoride in film form seems to be highly promising as it has the remarkable property of being practically free from the adverse effect of outdoor exposure. The films are highly oriented and can be oriented in both directions giving it also superior mechanical properties. Another striking polymer under development stage is polycarbonates a pencil of which, I have been shown, can be easily hammered through a thick board of hard wood. You can well imagine its future possibilities. Synthetic wool fibres in which sulphur chloride has been used and which resemble natural wool very closely in physical properties, are under way. Organic polymers of very high melting point, obtained by using closed rings in the main backbone of polymer structure, one example being $[-C_6H_4.\ CH_2.\ CH_2-]_n$, which is an isomer of polystyrene and melts near 360°C, are under development. High melting point of the same order is also being achieved by using metals like Be, Mg, Zi, Ni, etc., in the main polymer backbone taking help of their chelating properties.

CONCLUDING REMARKS

I hope I have been able to project to you a glimpse of some of the bright facets of high polymer science, the pristine beauty of the pattern of growth of macromolecules, and the prolific expansion of the area of contact with the life of the common man, this new science has made of late. The kaleidoscopic variety and the space-travel speed may have been a little disconcerting, but what else can you expect in the present world where people drive themselves mad at breakneck speed even towards sheer nothingness?

SECTION OF GEOLOGY AND GEOGRAPHY

President :—Dr. S. C. Chatterjee, D.Sc., F.N.I.

PRESIDENTIAL ADDRESS

THE PROBLEM OF THE ANORTHOSITES WITH SPECIAL REFERENCE TO THE ANORTHOSITES OF BENGAL

I am deeply conscious of the honour you have done me in electing me President of the Geology and Geography section of this session of the Indian Science Congress Association and I thank you most sincerely for this.

I have chosen for to-day's address a topic which had attracted my attention nearly thirty years ago when I first started research work in Geology and to which I have again reverted in recent years to re-study the problem in the light of the new work done in different parts of the world including India and the new exposures now available thanks to man's role as an agent of denudation.

The name anorthosite was first proposed by the Canadian Geologist Sterry Hunt in 1863 for a rock dominantly composed of 'anothose' or plagioclase feldspars. Rocks of this type have been most studied and their origin most debated in the Adirondacks region of the north-east United States. The anorthosites did not pose any problem until Bowen found out that the magma of anorthositic composition must have required a high temperature for which there is no field evidence.

He therefore postulated (1917) that the anorthosites did not form from the consolidation of a magma of anorthositic composition but by the gravitative accumulation of plagioclase feldspars from a gabbroid magma in a laccolithic body after the settling of mafic minerals to form gabbro and perioditite at the bottom, the residual liquid forming an overlying mass of granite or syenite. This was disputed by Cushing (1917), who maintained an younger age for the syenite-granite. Miller (1918 and 1929) proposed a modification of Bowen's hypothesis according to which anorthosite originated by the settling of early formed mafic crystals from a laccolithic or dome-shaped body of primary magma of gabbroic composition leaving an anorthositic mass beneath a chilled gabbroid border facies without the development of syenite-granite. He therefore regarded the syenite or granite as a later intrusive and presented field facts in support of this view.

Grout (1928) in a study of the Pigeon Point diabase sill in Minnesota suggested that the phenocrysts of plagioclase would rise in the magma chamber and would form a zone of anorthosite below the chilled contact. The main diabase below the anorthosite differentiated into a residual granite magma (red rock) at the top grading into diabase below through an intermediate alkalic siliceous rock. The residual granite magma may intrude the anorthosites to form rocks transitional between granite and anorthosite which Bowen considered to be a stage in the differentiation.

Later Grout and Longley (1935) brought forward evidence to show that in the case of the Duluth gabbro "the anorthosite formed early and was associated with the granite only after a further differentiation of the gabbro magma to a siliceous rest magma."

The theory of the origin of anorthosite by the accumulation of plagioclase crystals by flotation upwards did not receive any serious consideration but recently it has been revived in another form. In the Messum igneous complex of South-West Africa, where sheets of eucrite grade upward to extremely pure anorthosites, Mathias (1956) has suggested an origin of the anorthosites by upward accumulation of plagioclase crystals.

Since the anorthosite is composed of bytownite and the parent magma had a composition intermediate between eucrite and anorthosite and therefore was less dense than the pure eucrite magma, the bytownite crystals would tend to sink rather than to rise. The exact mechanism is uncertain but Mathias (p. 8) suggested the possibility of upward accumulation of plagioclase crystals by gas flotation by which bubbles of gas attached themselves to the early formed crystals, the gaseous phase having separated due to decreased pressure on intrusion in shallow depth. Another noteworthy suggestion made by Mathias to explain the absence of mafic counter parts is the assimilation or argillaceous material which is locally available. The early precipitation of plagioclase crystals will be induced by this process.

Grout suggested a mode of origin for the Adirondack anorthosites and syenite-granites and their relationship with each other similar to what he found at Pigeon Point. Grout and Longley (1935) interpreted the rocks transitional between anorthosite and granite as due to the disintegration of anorthosite by the intrusion of granite. Prof. Buddington, who has made the finest and the most thorough study of the Adirondack igneous rocks, had examined the Duluth gabbro along with Grout and agreed with the latter's interpretation. According to him the mixed rocks have the same physical characters as the syenite-anorthosite mixed rocks of the Adirondacks.

In the anorthosite area of St. Urbain in Quebec, Mawdsley (1927) found fragments of andesine crystals similar to the andesine of the anorthosite and also rare fragments of anorthosite in the syenite. Much earlier in 1909 Högbom explained similar mixed rocks in Sweden as formed in a similar manner.

Buddington had originally (1931) subscribed to the view of the common origin of anorthosite gabbro and syenite-granite of the northeast Adirondacks but later he changed his view after a more thorough study.

Balk (1930 and 1933) after a careful study of the Adirondack anorthosite, came to the conclusion that the granite-syenite series of rocks was derived from the original magma. "The rocks of the syenite series are considered as the frozen mother liquor of the magma". He found numerous shear zones which grade into the massive anorthosite. According to him, these shear zones represent the channels of the escaping mother liquor, which was expelled to form the masses of syenite-granite. The rocks of these shear zones are therefore composed of the constituents of granite such as microcline, albite and quartz together with labradorite both as phenocrysts and as finely crushed fragments and also garnet. This in essence is a modification of Bowen's original hypothesis. Bowen had also suggested that anorthosites of extreme purity would form by the settling of crystals and the squeezing-out of the residual liquor (1920, p. 160). Balk, however, thought that the parent magma was of dioritic composition and the intrusion was lens shaped. Like Bowen he considered the transitional rocks as really marking a phase in the differentiation in which the syenite-granite magma was not separated from the plagioclase crystals by the squeezing-out process. But while Bowen had advocated gravitative settling of the plagioclase feldspars, Balk thought that the mechanism of separation of the residual liquid from the masses of feldspars was governed by frictional forces between the stationary walls of the magma chamber, the suspended crystals and the mother liquor. The magma was continually pressed towards the south-west, and so the anorthosite had moved away from the gabbro of the north-east and the syenite had moved farthest.

In coming to these conclusions Balk depended upon the arrangement of the flow structures in the anorthosite and syenite. The protoclastic structure of anorthosite which is an almost universal characteristic has been explained by Balk as due to the movement of the clusters of the crystals such that 'all interstices in the crystal-filled chamber have been reduced to a minimum', and the crystals had undergone marginal pulverization. In proportion as the mother liquor was expelled, the flow structures were obliterated and the crystals were granulated along their edges by rubbing against each other.

Buddington (1939) argued in support of the younger age of the syenite-granite series and adduced a number of evidences in support of his view. As the relation between the anorthosite and the syenite-granite is fundamental to the problem of the course of magma differentiation by which anorthosite rocks were formed and of the nature of the primary magma, it will not be out of place to refer to some of the more important evidences which Buddington put forward. These are the large volume of the syenite-granite intrusive which could hardly have existed as interstitial residual liquids, inclusions of fragments of anorthosite and xenocrysts of andesine, and metasomatic alterations in the anorthosite caused by the thermal solutions from the adjoining quartz syenite. Moreover three periods of intrusion and a period of orogeny intervened between the formation of the anorthosite and the intrusion of the youngest granite which with its inclusions of andesine could not have been a residual liquid from the much older accumulations of plagioclase crystals.

Another significant difference between the concepts of Balk and Buddington is with regard to the origin and age of certain gabbros. Balk had described both saturated and undersaturated gabbros and thought that the residual liquids forming syenite-granite rocks are complementary to the gabbros including the anorthosites. Buddington found that while the saturated gabbros are similar to the anorthosite and have all gradations between them, the undersaturated gabbros with modal olivine form a discrete group without gradational contact and show definite intrusive relationship to the anorthosite. The rocks of the anorthosite series are all saturated or a little oversaturated and do not carry modal olivine.

A very significant observation made by Buddington is that the plagioclase of all the varieties of anorthosite and gabbros is of the same composition with minor variations. The variation of the quantity of mafic minerals giving rise to the different facies of the anorthosite -gabbro series may be "due to a relative concentration of the mafic minerals either in local bands" during flowage or as later upsurge of more mafic magma.

From the above considerations relating to the relationship of the younger syenite-granite series and the undersaturated gabbros to the anorthosite series varying from anorthosite to mafic gabbro through gabbroic anorthosite and gabbro, Buddington came to the conclusion that the primary magma of this series was of the composition of gabbroic anorthosite. This also corresponds to the composition of the border facies of the main intrusive and of the smaller outlying intrusives taken as a whole.

That a magma of gabbroic-anorthositic composition may form has been proved by the discovery of von Eckermann (1938) of two porphyritic dykes of anorthosite consisting of phenocrysts of labradorite in a hemi microcrystalline ground mass. The gap in the composition of the phenocrysts and the groundmass feldspar laths is almost the same as in the border facies of the Adirondack massif. The rock of the dykes has been named Kënningite by von Eckermann after the island of Känningen in Sweden where the dykes were found to cut the Archaean roof rocks of a sheet of anorthosite.

It should be mentioned here that as early as 1929, Miller had stated that settling of mafic crystals "is not necessarily essential to the explanation of the origin of the Adirondack anorthosite" and "suggested a gabbroid magma poor in the possibility of development of mafic minerals" which differentiated almost *in situ* with some magmatic movement before final consolidation. In 1943 in a review of the work of different workers, Miller showed that some of the saturated gabbros contain olivine, which is a hortonolite variety according to Buddington, and the undersaturated gabbros do not always contain olivine. He therefore suggested that the undersaturated gabbros may represent a very late differentiate of the same parental magma. Previously Miller had proposed a loccolithic form of the intrusive but in this paper he agrees more with Buddington that the main anorthosite massif may have the shape of a domical sill or may have been an asymmetric body with local domical structures in its upper portion.

According to Buddington (1936, 1939) there are in general two contrasted modes of association of anorthosite and gabbroic and troctolitic anorthosite: (a) as a major facies of differentiated stratiform sheets or lopoliths such as the Bushveld and Transvaal in South Africa; Sierra Leone in West Africa; Stillwater in Montana; Bay of Islands in Newfoundland and as minor facies of layered gabbroic sheets such as the Duluth and Pigeon Point in Minnesota; Cullin Hills in the Islands of Skye etc.; and (b) as large or small masses without visible stratiform characters and with areal domical structures in the roof such as the Adirondacks ; Morin and St. Urbain in Quebec ; and many other bodies in different parts of the world.

From a comparative study of the different rock units of the layered sheet intrusions which show a systematic variation in the vertical sequence from an undifferentiated gabboric chill facies of the floor to granophyre or granite at the top through ultrabasic rocks with or without chromite layers ; norite or olivine gabbro and anorthositic layers within the gabbroic zones or between the gabbroic and the granitic layers, Buddington (1939, 1943) postulated that these may be analogous to the layered structure of the earth itself. A magma consisting of 80 per cent andesine-labradorite ($Ab_{50}An_{50}$) which is the average composition of the feldspars of the Adirondack anorthosite, and 20 per cent pyroxene will form from the partial melting of a crustal layer of bytownite anorthosite composed of 92 per cent bytownite-labradorite and 8 per cent pyroxene. From an interpolation of the diopside anorthite-albite equilibrium diagram it is inferred that this partial melting may take place at about 1350°C. The restriction of anorthosite of the Adirondack type to the pre-Cambrian finds an explanation in this view since derivation of magmas by partial melting may be formed only once from a given mass and this might have happened during the pre-Cambrian, when temperature gradients were higher, where there was local rise of the isogeotherms.

The temperature of partial melting given above (1350°C) is for a dry melt. It is quite likely that the presence of volatiles will considerably lower the melting temperature. We have now available experimental data on the effect of water on the melting point of anorthite-diopside mixtures. Yoder (1955) found that at water pressure of 5000 bars the eutectic is reached at 1095°C with 73 per cent anorthite and 8·8 per cent of water compared to the eutectic at 1274°C for the dry system with 42 per cent anorthite. By making reasonable interpolations from the above data and the data for the albite-water system (Goranson, 1936), Buddington (1957) showed that mixture of 80 per cent plagioclase of composition $Ab_{50}An_{50}$ and 20 per cent diopside, which he had assumed as the type of parent magma of the Adirondack anorthosite and capable of forming at 1350°C, will be completely molten at 1230°C with 4 per cent of water. The liquidus for the cotectic will be about 1120°C with 70 per cent plagioclase of composition $Ab_{50}An_{50}$. Since plagioclase would crystallize before the composition of the melt reached the cotectic, the relative concentration of water in the melt would increase to 6 per cent and the cotectic temperature would be about 1060°C with 77 per cent plagioclase ($Ab_{50}An_{50}$) and 23 per cent diopside. The temperature of final consolidation may be as low as 950°C or even less because of the increase in the concentration of water and the presence of other volatiles in addition to iron oxide, titanium and phosphoric acid. Since the gabbroic anorthosite magma must have crystallized partially before emplacement as evidenced from flow structures and marginal granulation, and must have contained considerable amounts of water and other volatiles, the actual intrusion temperatures could not have been so high as to have caused contact effects.

That the magma from which anorthosite was formed was rich in volatiles is seen from the presence of giant pyroxene crystals as large as 8 inches in width and 2 inches in length in large augens of andesine as recorded by Balk (1944, p. 300) in the Adirondacks. Both appear to have been precipitated from volatile rich liquids. Balk refers to similar giant pyroxene crystals in the Egersund anorthosite massif of Southern Norway.

In the San Gabriel anorthosite of California, Higgs (1954, p. 186) has found giant plagioclase crystals as large as 22 inches by 68 inches and hypersthene crystals as large as 10 feet in length. The concentration of water in the residual magma was so high in this case that, according to Higgs, release of pressure by some means caused internal explosive shattering of the almost consolidated anorthosite mass and also caused the granulation of the minerals.

In their study of the anorthosites of the Colony complex near Freetown, Wells and Baker (1956, p. 157) explained the coarser texture of the leucogabbros and anorthosites compared to the troctolites as due to the concentration of water in the upper layers of each unit of the layered mass. The "developments of gabbro-pegmatite in the upper layers, and the autointruisive character of some of the anorthosite bodies" lend support to this view.

Pegmatitic anorthosite has been recorded from the Adirondacks (Alling, 1932, p. 206 and Wheeler, 1942, p. 68) and many other areas. According to Alling the pegmatites "support the view that there may have been sufficient liquid associated with the labradorite crystals in the production of anorthosite".

From the intensive widespread metasomatism of the country rock marble beds in the Adirondacks, Buddington envisages a relatively high volatile content for that gabbroic anorthosite magma (1957).

It should be noted that the Adirondack anorthosites and associated rocks have undergone metamorphic reconstitution.

It will appear therefore that the main problem of the anorthosite as envisaged by Bowen that an anorthositic magma would require a high temperature for its existence for which there is no field evidence and the complete lack of effusive equivalents has now been solved by the abundant field facts of the existence of a gabbroic anorthositic magma, presence of water and volatiles and the results of Yoder's experiments. This does not preclude the formation of anorthosite layers in stratiform sheets by the settling of plagioclase crystals from ordinary gabbroic magma. This is what has been described as the accumulative type (Barth, 1952, p. 226).

METAMORPHIC AND METASOMATIC ORIGIN OF ANORTHOSITE

During the last several years another aspect of the anorthosite problem has come to the fore and that is the belief, supported by field facts in most cases, that many of the anorthosite bodies are due to metasomatic and metamorphic processes.

According to Ramberg (1948, p. 567) there is a tendency for Si, K, and Na to diffuse upward through the crust and a tendency for the heavier elements to migrate downward. By the squeezing out of oxygen, silicon, potassium, and some sodium, plagioclase of intermediate composition remains behind together with pyroxenes, garnet, olivine and ore minerals. Thus there is, according to him, "a thermodynamic tendency to separate anorthositic massifs or a more or less continuous anorthositic shell below a certain depth in the crust". Anorthositic rocks are assumed to belong to the zone of granulite facies ' which only crops out in deeply eroded parts of old fold mountains" and underlies the zone of epidote-amphibolite and amphibolite facies. According to him large anorthosite massifs such as those of Egersund in Norway and the Adirondacks appear to be situated below the quartzose granulite facies gneisses.

Again in 1952 in his book "The Origin of Metamorphic and Metasomatic Rocks" (p. 262, 264) Ramberg suggested that anorthosites might form below the level of granitization in geosynclines by large scale basification and "calco-ferromagnesian silicates are more stable than the granodioritic materials below a certain level in the earth's crust".

It is true that rocks of the granulite facies such as charnockites and enderbitic gneisses are often found associated with anorthosite, and gabbroic anorthosite itself develops a granulite facies assemblage by subsequent metamorphism, but Ramberg doubts even the original magmatic nature of these rocks.

Barth, once a believer in the igneous origin of anorthosites, has radically changed his view after a study of the Sorlandets anorthosite in Norway in which he made a number of observations which can only be explained by a metasomatic origin (1941). I am grateful to Prof. Tom

Barth for sending me an English translation of some of the salient points from his paper which I am summarising below:

(a) The large dimensions of some of the crystals, crystals as large as fist or as a head and even measuring 110 cm. have been observed. As the crystals do not show any zoning, they must have required slow cooling during almost isothermic conditions for a very long time and then must have been separated suddenly from the residual melt quite effectively.

(b) The occurrence of underformed porphyric crystals of bluish or white andesine in a foliated and gneissic anorthosite groundmass which appear more like porphyroblasts than phenocrysts formed at an early crystallization phase.

(c) There is not only peripheral foliation along the contact but "in certain places in the middle of the area the foliation forms folds, and such a fold may be surrounded by a perfectly massive rock." The massive rock seems to have lost its gneissic character and fold structure by recrystallization.

Barth not only believes in the metasomatic origin of the anorthosite of Southern Norway but also believes that the Adirondack anorthosites owe their origin to metasomatic processes (personal communication).

It may be noted here that Balk after a restudy of certain areas in the Adirondacks thought that the large andesine and hypersthene crystals which were considered as precipitated from volatile rich fractions (1944) might have formed by metasomatism (personal communication).

In his book "Theoretical Igneous Petrology", published in 1952, Barth stated definitely his view in favour of a metasomatic origin of anorthosite (p. 229). From the fact that anorthosites, like granites and gneisses, form "intrusions" of batholithic dimensions and from the other previously mentioned observations, Barth suggests the possibility of their origin by metasomatic anorthositization of batholithic dimensions by processes similar to those which give rise to metasomatic granitization.

Sorensen (1955) has described an occurrence of anorthosite in West Greenland in which the anorthosite is folded with the surrounding gneisses forming a syncline in several places and are associated with paragneisses, amphibolite with skarn and mica-schists. The plagioclase is more basic than is normal for the pre-Cambrian anorthosites in general.

According to Sorensen the anorthosites may be of sedimentary origin from the metamorphism of calcareous sediments under granulite facies conditions.

The most radical idea is that of Van Biljon (1949) according to whom the rocks of the different units of the Bushveld complex pass on into a series of sedimentary strata. He considers the pyroxenites, norites, and anorthosites, etc., as metasomatized sediments of appropriate composition.

Michot's ideas on the origin of certain Norweigean anorthositic rocks have been adequately discussed by Buddington (1957). For the anorthosites of Madgascar Michot (1957, pp. 41-49) thinks that a part of the anorthosites has been formed from the metamorphism of sedimentary material while the rest has formed from original igneous material.

Buddington has recently (1957) reviewed some of the above views and from the study of the phase petrology of the plagioclase, pyroxene and titaniferous magnetites of the Adirondacks and many other anorthosite bodies, came to the conclusion that the Adirondack type of anorthosite and the anorthosite of stratiform sheets were formed at magmatic temperatures.

It seems, however, possible that even as granite may form by various processes such as by crystallization from a magma formed either by differentiation or by differential melting in a tectogen or by granitization processes, anorthosite may also be polygenetic. It is therefore necessary to establish criteria for igneous origin as has been done by Buddington and to apply these to the petrographical characters of rocks of an individual area before coming to a definite conclusion.

THE BENGAL ANORTHOSITE

The occurrence of anorthosites and norites near the south border of the Raniganj coalfield was first recognized by Holland who referred to it in his Memoirs on the Charnockite Series (1898, p. 208). It is worth while to quote the brief but very important observations made by Holland:

"The Norites are fine-grained and granulitic, sometimes foliated and sometimes showing an occasional garnet. The labradorite rocks are very variable in the size of their crystals, the ferromagnesian constituents which occur in comparatively small quantities, include an occasional olivine with well defined reaction rims."

The present author undertook a study of these rocks in 1928 and a short preliminary note was published in 1929. The prevailing idea was that the anorthosites are found only locally near Raniganj, but an attempt to trace the boundary revealed its large area. The main outcrop is rather narrow with width of about five or six miles for much of its length and broadens towards the east. The original extent is unknown since it is cut off by faults in the northern part towards the east which mark the boundary of the Raniganj coalfield and abuts against the Damodar river in the north-east and part of the east side. The bend in the course of the Damodar river here may be fault-guided since Gondwana strata crop out on the other side.

The results of the detailed study were published in 1936. Since then the area has been thoroughly surveyed by Hunday of the Geological Survey of India (1953, pp. 23-24 and 1954, p. 35). Hunday apparently agreed with the author's observations and recorded a few more outlying outcrops and dykes of "anorthosite-like rock in the granite country some distance away from the main exposure", which confirm the author's previous observations of the occurrence of anorthosite dykes in gneissic country rock south-west of Kustolia (23°, 28′, 30″; 87·5°, 30′) ; behind the Inspection Bungalow of Saltora (23°, 31′, 30″, 86°, 56′, 15″) and a few other places.

This is one of the evidences in support of the younger age of the anorthosite compared to the Bengal gneiss. The discovery by Hunday of small patches of white coarse-grained anorthosite in several outlying places, some rather far away from the main mass as near Guniada 23°, 9′; 86°, 45′) just east of the boundary between Bankura and Manbhum districts, shows that the anorthosite body actually occupies a much larger area than is visible. In the classification of the rock formations, however (1954, pp. 34-35), the anorthosite is shown as older than the granite-gneiss and various composite-gneisses and schists. All the granite-gneisses in the area are, however, older than the anorthosite and more evidence has been found in favour of this age relation.

Since the publication of the previous work by the present author, much work has been done in other countries and an alternative metamorphic-metasomatic theory of origin has been proposed by many eminent authorities so that a revision seemed justified. Much new field data have now been collected during the re-study undertaken by the author because of the numerous fresh exposures now available since many of the hummocky masses have been broken up for ballast for work in connection with the Damodar valley projects.

AGE AND INTRUSIVE RELATION OF THE ANORTHOSITE

It should be mentioned, that, while the main conclusions previously arrived at remain, an important revision has been with regard to the rocks which were called grano-anorthosites in the 1936 work (p. 10). These were thought to have been due to the assimilation of anorthosite by granite. But clear field evidence has been found to show that the granitic gneisses within the anorthosite, whether as dykes or as sheets with irregular contacts, are all inclusions. A little to the east of the bridge on the Chouphari stream on the Raniganj-Bankura road, is an excellent outcrop of anorthosite with irregular patchy and bouldery inclusions of gneiss. Even a half emply socket once occupied by an inclusion of gneiss can be seen. The grano-anorthosite type of hybrid rock is but the junction between anorthosite and granite-gneiss.

The gneissic granite is in places a red granite but in other places it is much darker with alternate narrow light coloured bands. The darker bands have a curious resemblance to the surrounding dark anorthosites. Microscopic examination of thin sections taken across the junction leaves no doubt about the intrusive nature of the anorthosite in the gneiss. The anorthositic portion is without any sign of stress and directional arrangement of the minerals while the gneissic portion has evidently a metamorphic fabric with alternate bands of quartz and orthoclase or microcline with some micro perthite, all more or less crushed. Near Mochrakhend (23° 3′; 87° 9′) there are bands and isolated fragments of granite gneiss in the anorthosite. Near these inclusions are often found pegmatite veins with pink feldspars both in the gneiss and in the anorthosite along joints. This renders the determination of the age of the pegmatite veins somewhat difficult and a possible explanation is that the pegmatites are due to local palingenesis.

Near the south-eastern boundary of the anorthosite on either side of the cart road to Maliara, injections of anorthosite and the dark granulitic norite are found in the gneiss.

Similar phenomena is seen along the northern boundary towards the west behind the Inspection Bungalow of Saltora. The anorthosite here has intruded into a hornblende gneiss which in its turn occurs in the granite-gneiss and may be an old intrusive dyke now metamorphosed. At one place the gneissic country is traversed by a number of pegmatite and quartz veins and a thin band of plagioclase rock.

Thus from the (a) occurrence of intrusive dykes and apophyses of anorthosite and its darker phase, the granulitic gabbro and norite in certain localities in the surrounding Bengal gneiss, both in the north and in the south, and of (b) inclusions of the same type of gneiss within the main body of the anorthosite, and (c) the highly metamorphosed character of the gneisses, the anorthosite mass is considered intrusive into the adjoining Bengal gneiss, gneisses and, biotite sillimanite schists and quartzites.

FIELD RELATIONS OF THE DIFFERENT TYPES OF ANORTHOSITE AND THEIR STRUCTURAL FEATURES

The intrusive rocks belonging to the anorthosite series may be classified into the following types:—

(1) White variety of anorthosites which are almost free from ferromagnesian minerals and may be described as Labradorite rocks where they are unaltered by metamorphism.

(2) Anorthosite of grey variety containing not more than 5 per cent of ferromagnesian minerals.

(3) Anorthosite-gabbros containing more than 5 per cent but less than 15 per cent of ferromagnesian minerals.

(4) Olivine Norite.

(5) Dark coloured granulitic norite and gabbro.

The white anorthosites owe their lack of colour to the absence of clouding and schiller inclusions in the feldspars. These are more common and are found throughout the area, particularly along the northern part. They are more susceptible to weathering and therefore their outcrops are few and the area forms low ground. The exposed outcrops are more or less, kaolinised and blocks of fresh rocks are found scattered over the uplands. The grey and dark varieties are more resistant to weathering and form a belt of high land with hummocky masses, tors and even low hillocks in the south extending east to west across the Bankura road in the eastern part. The villages Mochrakhend and Narainpur are situated in this belt. The white anorthosites differ from the grey variety in two other respects: They do not show as nicely the lineation which is almost a characteristic of the latter. But they have often streaks and layers of dark minerals. The frequency of these streaks and schlieren increases near the thicker bands of the dark constituents and the quantity of the femic constituents in the white rocks also increases near these bands. All these suggest a segregative tendency of the dark minerals in the anorthosite. The two rocks interpenetrate each other in such a way that it seems as if they have a mutual intrusive relation. The probable sequence of crystallization is that the dark gabbro which formed by the segregation of the mafic constituents with some plagioclase began to solidify earlier and caught up portions of the feldspathic liquid which appear as white streaks, bands and veins. Where there was relative movement between the black rock and the white more plastic rock of the vein, the latter was bent, contorted and folded in the manner of ptygmatic veins. The amphibolization of the pyroxenes in both the dark and the white rocks was a later effect. Ptygmatic folding formed in this way does not conform with the ptygmatic folding described in geological literature which is considered typical of metamorphic or "granitized complexes in which remobilization has taken place (Godfrey, 1954 p. 378).

The anorthosite is not only foliated near the dark intrusion but is epidotised along certain bands with development of secondary quartz. Away from the stream on higher ground the anorthosite is compact and well jointed and has bluish white colour.

The white anorthosite passes into the dark anorthosite rather imperceptibly. As has been said before the dark colour of the rocks is due to the schillerisation of the feldspars. But it is also due to presence of a larger amount of ferromagnesian minerals.

On account of the dull grey colour of the rocks there is a superficial resemblance to the intermediate charnockites. The rounded outcrops have a characteristic pitted appearance due to the removal of the femic minerals such as biotite, pyroxene and garnet from the exposed surfaces. The rocks are highly variable in texture and every gradation is found from a uniformly fine-grained variety to a coarsely crystalline variety. The more general type is a porphyritic or porphyroblastic rock in which plates of labradorite occur in a finely granulated mass of plagioclase feldspar.

On the northern bank of the Choupbari near the bridge on the Raniganj-Bankura road, a very interesting outcrop is exposed.

Here there is a dyke of the dark granulitic norite resembling a fine grained dolerite in colour and texture, which has a roughly east-west trend, just at the northern edge of the Choupbari stream dipping to the north. The dyke swells into an ellipsoidal mass which is slightly tilted to NNE and is flanked on the north side by foliated and contorted white anorthosite in which the foliation bends round the ellipse. This is a case of forcible injection and subsequent metamorphism. The white anorthosite has lines and strings of the dark rock which increase near the dyke. The triangular outcrop of another swell abruptly cut vertically by a joint shows its pinch and swell character and the narrowing width with depth shows that it is due to auto-intrusion of a segregated mass. Near this again there are veins of the white anorthosite in the dark rock and the veins become highly tortuous resembling ptygmatic veins. The dark rock has been metamorphosed to an amphibolitic type of rock where these veins occur and might be easily mistaken for older country rocks. Careful microscopic study was therefore made of specimens collected at short distances from one another and it was found that there are different stages in the amphibolisation of the monoclinic and rhombic pyroxenes of the granulitic norites so that the rocks are completely amphibolized. Just as, near the dykes of the dark granulitic rocks, there are thin streaks of the dark minerals in the white anorthosite, so that the rock resembles a streaky anorthosite or a banded gabbro, similarly, within the mass of the black bands there are fine streaks and veins of the white rock. A beautiful instance is found in the stream behind Saldoba (23° 30′ ; 87° 5′). There are veins of quartz or of quartz and feldspar in the white anorthosite. The whole complex is sheared and contorted or foliated. This intimate association of anorthosite and dark granulitic gabbro has been noted in many places in this area.

These phenocrysts or porphyroblasts of feldspar in places assume large dimensions measuring a few inches in length. Crystals exceeding six inches in length are rare.

The rocks have a regular and persistent system of joints which have caused the formation of many tors and rectangular blocks and slabs. The direction of the more prominent joint varies from N.W.-S.E. to N.N.W.-S.S.E., and N.N.E.-S.S.W., E.N.E.-W.S.W., and E.S.E.-W.N.W., joints are also found. It seems that the joint varies a few degrees both ways from a general E.-W. direction. The joint at right angle to this direction is less prominent. Several dyke-like inclusions of gneiss were found to have a NW-SE and N.S. trends.

Besides jointing the rocks have a marked linear parallelism caused by the parallel arrangement of the feldspars. The general direction of the lineation is SE-NW and the largest faces (010) of the feldspars often lie in the vertical plane which may also be dipping at high angles to the north or north-east. Locally the direction of lineation may change to N.N.E.-S.S.W. but the regional trend is S.E.-N.W. This may seem at first sight to be the result of metamorphism by which the feldspars have assumed a common dimensional orientation by plastic flow as has been suggested by Buddington (1939, p. 307), for the linear parallelism of the feldspars in the Adirondacks which Balk had considered as a flow structure and from the direction of which and the direction of the planer flow and other structural data tried to visualize the direction of the movement of the magma from the north-east obliquely upward to the south-west. Buddington had supplemented Balk's data by additionai data based upon his own observations in the field in the north-eastern prong and part of the north-west border of the Adirondacks and found that in certain regions the linear structure corresponds approximately to the axes of minor folds. "The data obtained in the southern half of the massif do not yield a similar picture, and a final decision on this area must await a more detailed study" (P. 311).

This is a very important subject as on its solution depends the entire picture of magma tectonics as envisaged by Balk. According to Buddington plastic flow of solid rock along pre-existing directions and surfaces which were originally determined by magmatic flow or banding may have given rise to the lineation. As has been remarked by Turner (1948, p. 314), "If Buddington is correct the foundation of Balk's thesis is seriously impaired if not destroyed".

In the anorthosite mass described in this paper, the linear parallelism is believed to be a primary feature from both field and microscopic evidence. In the field the lineation is not found throughout the mass and is very inconspicuous in the white anorthosite. Further, it is confined only to the anorthosites and is not found in the gneisses and granitic rocks which are considered to be older. The study of thin oriented sections shows that the parallelism may be best described as igneous lamination (Wager and Deer, 1939, p. 271).

This does not imply that the anorthosites are unmetamorphosed. In fact there are many field evidences of subsequent cataclastic and regional metamorphism. The effect of the former is much more localised than that of the latter. Cataclastic deformation was caused by shearing movement along certain narrow zones which are now marked by veins of epidote group of minerals and scapolite indicating the accession of water and other volatiles. Although generally free from garnet, the rocks are full of pink garnets in certain places particularly in the area to the west of the Bankura road near Nandanpur where the white rock is marked by irregular patches and streaks of garnet and titaniferous magnetite.

The gabbroic type of anorthosite has no definite areal distribution but is found locally in the midst of the grey anorthosite such as near the locality noted in the previous paragraph and along the Maliara road. The dark minerals are often concentrated in patches but may also occur in dark bands in the grey or white rock forming a banded or layered rock. Between Mochrakhend and Kalipathar (23° 30′; 87° 10′) near the road to Maliara, banded and gneissose types are found some of which are garnetiferous in which the garnets show a linear arrangement. The main mass is bluish compact anorthosite in which large feldspars are seen in certain zones and in irregular patches. Some outcrops have dark blotches which appear to be aggregates of pyroxene, garnet, biotite and amphibole. Here a pegmatite with white feldspar is mixed up with the anorthosite with an indefinite contact. Pegmatite of this type has not been found elsewhere.

Beyond Kalipathar there is a large outcrop of granite-gneiss between Barasal (23° 30′; 87° 11′) and Rajarampur. It is here that the anorthosite has sent apophyses into the gneiss.

Olivine norite has been found in only two localities : one in the Chauphari valley near the road to Maliara from Mejia or Raniganj and the other south of the boundary fault in the north near the hillock of Panchet sandstones.

In the midst of the grey coloured anorthosites, the dark bluish olivine norite strikes one's eyes as a different rock. The rocks of the first locality are characterized by large plates of plagioclase and flakes of biotite and patches of serpentinized olivine.

The dark granulitic rocks resembling fine-grained dolerite occur as schlieren, bands, ellipsoidal lenses and dykes. These occur throughout the anorthosite body and also in the adjoining crystalline terrain. Owing to their superior resistance to weathering they form ridges and low hillocks with innumerable spheroidal boulders of various sizes on the surface. The rocks are hard, fine-grained and finely-jointed but there is a variation of texture from the fine-grained granulitic type to a coarse-grained massive type.

In some dykes the rocks appear more like a hornblende gneiss or a compact amphibolite. Some are also garnetiferous. Most of the dykes have an east-west trend with variations both to the north and the south and in some the strike is north-west to south-east. This coincides with the general strike of the major joints in the anorthosite and the direction of foliation of the older gneisses and schists. The dykes in some cases are inclined towards the north. Usually the dykes have clear-cut junctions with the anorthosites but there are instances where they appear as small lenses and irregular sheets with ill-defined terminations. The contact shows evidence of deformative movement.

All the three varieties of anorthosite, namely, the white type, the dark type, and the gabbroid type are represented among the dykes of anorthosite, but the first type is more common. These dykes are fairly abundant in the region lying to the west of Kustolia at a distance of about a mile. The anorthosite forms ridges of tall slabs of compact rock which dip at high angles towards the north. The strike varies from E.-W. to E.S.E.-W.N.W., parallel to the direction of strike of the intruded granite-gneiss. Other less conspicuous dykes occur between the major dykes and the road. Farther to the south east, east of Barkona (23° 27′; 87° 4′), a succession of anorthosite dykes and Bengal gneiss which has been cut up by the dykes is found. Other dyke occurrences have been mentioned previously. The anorthosite is of the white type and has a gneissic appearance due to the parallel orientation of the constituents which does not appear to be a primary feature. Both the anorthosite and the granite-gneiss are intruded by a dark gabbro now a hornblende gneiss. Dykes of a fine-grained aplitic rock occur in the same manner as the anorthosite.

The main anorthosite outcrop becomes narrow in this western part and gradually thins out towards the west and is not seen beyond roughly a north-south line from Santuri (86° 5′ 30″; 23° 32′). In the foreground of the hillock behind Santuri is an intrusive band of coarse-grained foliated anothosite with phenocysts (?) of the plagioclase in a white groundmass.

Dykes of dark anorthosite, and anorthosite-gabbro are found in the gneiss south of Bhatuikhend (23° 26′ 30″ ; 86° 49′).

A dyke of titaniferous magnetite has been found in the anorthosite near the road to Saltora from Mejia, west of Saltora.

Dykes of anorthosite have been recorded from California (Miller, 1932), Adirondacks (Alling, 1932), and a few other places. The dykes described by Alling are Anorthosite pegmatites.

PETROGRAPHICAL NOTES

An attempt has been made to study the composition of the feldspars and the nature of the mafic constituents by systematically sampling specimens from different parts of the main anorthosite outcrop. It is not possible to deal with the large volume of petrographical data which has been collected by the study of many thin sections of the different rock types in an address of this nature. The more salient features will therefore be presented briefly here.

Though there is no marked difference in the physical appearance of the different types of the anorthosite rocks, certain varieties can be made out from a study of the thin sections as also from a careful megascopic examination. There are two main textural varieties of the anorthosites of the greyish type and some of the white type which can be made out megascopically.

The common texture is granular with porphyritic or porphyroblastic rough cleavage plates showing out, surrounded by, and set in a granular base. In the other type there is a marked linear parallelism, with a platy parallelism which varies in the degree of perfection. Often on the same platy surface many of the tabular feldspar laths have a random orientation. In others the planer and the linear parallelism are both marked. Marginal protoclastic granulation is more common around the feldspar phenocrysts of the first type which have irregular outlines, but in many sections the anhedral feldspar individuals occur in perfect juxtaposition without granulated margins. Many of these anhedral feldspars are untwinned, though some sections may be parallel to 010 face and show beautiful schillerization under crossed nicols. In position of extinction the surface appears full of bronze-like shining wisps of a micaceous mineral with a roughly parallel arrangement. The borders are free from inclusions. Besides the semi transparent micaceous wisps (micaceous titanic ore), there are inclusions of biotite and amphibole. Apart from these large inclusion there are inclusions of numerous black dots and dark rods and plates arranged in parallel lines which give the mineral a clouded appearance. The clouding is patchy owing to the patchy distribution of the dots. The rods may be of rutile and the dots and plates of ilmenite, since the plates and dots coalesce to form small aggregates of ilmenite.

When the schiller inclusions occur in the twinned feldspars, one set of the inclusions are seen to occur in the twinning planes while the lines of the other set make angles of 65° with with the former, but angles of 54° and 45° have also been noted. The inclusions also appear to occur along the most prominent 010 cleavage and make angles of 62·5° with the 001 cleavage on 010 face.

The smaller feldspar individuals round the larger plates do not generally show the schillerization. According to Adams (1885, p. 85) the disappearance of the inclusions is related to the granulation. This assumes a primary origin of the inclusions but from several other characters the inclusions and the clouding in these rocks appear to be a metamorphic effect and the lack of these inclusions in the smaller grains may be due to the greater facility of migration of the foreign inclusions in the larger plates, along their twinning or cleavage planes.

In the garnetiferous white anorthosites garnet forms a corona round the plates of titaniferous magnetite separated by a zone of secondary feldspars which are full of dusts and granules of iron-ore. In some sections the garnet rim is against the magnetite without the zone of feldspars.

*The phenomena of the corona garnet formation and the clouding of the plagioclase seem to be related. Both appear to be due to regional metamorphism. Poldervaart and Gilkey (1954, pp. 87-88), after a thorough study of the phenomenon of clouding of plagioclase, have stated that the clouding may be due to both thermal and regional metamorphism. In this area regional rather than only thermal metamorphism seems to be the cause since it has to be considered along with the other evidences of regional metamorphism found in the gabbroic anorthosites.

The majority of the feldspars are twinned. Twinning on albite law is more common but often pericline twinning is also seen along with the albite twinning.

In the anorthosite of the second textural type, i.e., the lineated type, the albite twinning is more regular, marginal granulation is rare and the feldspar laths have more idiomorphic outlines. The twinning is very irregular in the first type of anorthosites. Combined albite-Carlsbad twinning is very common in both the types and is seen in almost all the thin sections and as many as ten have been counted in one section.

The twin lamellae when imperfectly developed, mostly in the first textural type of anorthosite but also in the second type, often do not extend over the entire section. The lamellae do not have the same thickness throughout and taper and finally die out. When an individual is bent with wavy extinction, the twin lamellae are bent conformably with the outline of the crystal. There may be a change in the interference tint due to the change in the orientation of the lamellae at the curvature. Pericline twinning develops at the hinges of the bends. The smaller grains are not so well twinned.

Fracturing of the plagioclase feldspar is seen in both the types of anorthosite. The lines of fracture are filled up with granules of later feldspar. The twin lamellae end at these fractures and new lamellae appear on the other side of the fractures. This shows that the twinning developed after the fracturing. Another interesting feature of the twining is the gliding of some of the lamellae of one individual. The bending of the lamellae along with the bent outlines of the crystals shows that twinning developed during the bending of the crystal by the pressure of the adjoining crystals.

There is some difference of opinion about the period of development of twinning. According to Donnay (1943, p. 1651) twinning is developed during the growth of the crystals while Emmons and Gates (1943) and Emmons and Mann (1953, p. 43) believe that twinning "forms late in the history of the crystal". Subramaniam (1956, p. 338) in his study of the Sittampundi rocks finds support for Donnay's views. But from the evidences of bending and fracturing of crystals and their relation to twinning which have been noted above, and the tapering abruptly ending nature of the lamellae, it can be inferred that the twinning in these anorthosites was developed after the growth of the crystals but before the final consolidation of the rock since the fracture filling and the formation of the smaller crystals of second generation took place in between. These evidences and conclusions are in full accord with those given by Wells and Baker (1956, p. 151).

As regards the composition of the feldspars it may be stated that with minor local exceptions the feldspar is a labradorite with about 65 per cent anorthosite. The optic axial angle in the majority of crystals from different localities in the eastern part of the area falls near 80°, more near 78° with a positive sign. The average refractive indices are:

$\alpha = 1{\cdot}559$, $\beta = 1{\cdot}563$ and $\gamma = 1{\cdot}566$ to $1{\cdot}567$. The above data agree with the average maximum extinction angle in the zone normal to 010 measured in numerous sections from different varieties and localities which is 37°. Buddington found that the plagioclase in the Adirondack anorthosites has an uniform composition (1930, p. 217). Zoning in the plagioclase is also seen in some of the feldspars of the white anorthosite.

In the anorthosites which have suffered from cataclastic metamorphism epidotisation has taken place in these zones subsequent to the crushing. The feldspars show the development of several secondary minerals such as epidote, zoisite, clinozoisite and scapolite. The composition of the feldspars has undergone a change towards the more sodic type by a loss of calcium which has entered into the composition of the epidote minerals. This is seen by a lower refractive index of the plagioclase near the epidote and its different optic axial angle.

Part of the twinned feldspar has become isotropic and small crystals of dickite are found in the midst of the zoisite and clinozoisite. Other secondary minerals are chlorite and scapolite. The latter has a preference for the junction lines between the feldspars. The formation of the epidote minerals is concomitant with the chloritization of the small quantity of amphibole and pyroxene present in these rocks as has been shown by Harpum (1954, pp. 1076-1078). In the granulitic zones between the larger feldspars, myrmekite of the brain coral type has developed in the white anorthosites. All these characters show the influence of later accession of hydrothermal solutions and volatiles.

The ferromagnesian minerals are the same throughout the mass but all of them are not found everywhere. The primary ferromagnesian minerals are rhombic pyroxenes: enstatite, hypersthene, and also bronzite ; monoclinic pyroxene, and magnetite, besides olivine in the olivine norite. Hornblende is widely prevalent and in some varieties of anorthosites it is the only ferromagnesian mineral present. Part of the hornblende may be primary but in most thin sections the preservation of relict pyroxenes shows that it has formed by later amphibolization. In the Adirondack anorthosites, Buddington found the hornblende to be secondary (1939, p. 33 and 1952, p. 49). Buddington's observation that the pleochroism of hornblende in garnetiferous rocks from bluish green to green and in non-garnetiferous rocks from dark olive green to brown (p. 53) has also been found to hold true of the hornblendes in these rocks. A little hornblende has formed as a corona round magnetite together with biotite and garnet.

In the pyroxenic varieties, relict ophitic texture is seen in those varieties which have not been totally reconstituted. Both bronzite and diallage are highly schillerized. In the reconstituted rocks, the texture becomes granulitic. Hypersthene has developed secondarily after bronzite and diopside. Garnet has formed by reaction between feldspar and pyroxene. Granules of pyroxene and garnet are seen set in a feldspar base whose composition has undergone a change by the reaction. In some rocks, the aggregates of monoclinic and rhombic pyroxenes are enclosed by a ring of small garnets forming a corona. There is plenty of biotite and secondary amphibole pleochroic in bluish green near these aggregates. Because of the crowding together of these minerals in patches, the rocks have a blotchy appearance with dark greenish and reddish patches in a feldspathic base. Another secondary mineral is apatite.

During a subsequent period of retrogression, the feldspars and the ferromagnesian minerals have been altered to epidote minerals and chlorite, other secondary minerals are sericite, scapolite, a little sphene and calcite.

The olivine norites show two very interesting features, namely, the development of a three-ply and in some cases four-ply corona round olivine, and dense clouding and schillerization of the feldspars and pyroxenes. In his previous paper the author had thought that the first two rims of hypersthene and enstatite were formed by magmatic reaction and the formation of garnet and amphibole was considered as due to subsequent metamorphism. Shand (1945) showed that coronas are not magmatic but are formed by thermal metamorphism. A contact metamorphic origin is accepted by some workers and a regional metamorphic by others. The latter seems to be more in harmony with the field and laboratory observations in this case. In a recent study of many coronites from India Murthy (1958) concludes that regional metamorphism at comparatively high temperatures, under water-deficient conditions, produces coronas. According to Murthy, with small amounts of water only rhombic pyroxene coronas are formed. With increasing amounts of water amphibole coronas are formed by reaction with the plagioclase which becomes now unstable, and with further increase of water garnet coronas are formed. In his study of the coronites in troctolites associated with anorthosites, Osborne (1949) and in the study of the system diopside-forsterite-anorthite, Osborn and Tait (1952, p. 432) have shown that the assemblage calcic plagioclase and magnesian alivine turns into diopside, enstatite, spinel and olivine or (in the experimental system) into pyroxene, spinel and plagioclase under appropriate conditions. Calcic plagioclase and magnesian olivine form a metastable assemblage at moderate temperatures in the experimental system. The low temperature stable assemblage forms below 900°C, a figure which agrees with the temperature of corona formation suggested by Murthy after a full discussion of Yoder's data. In the present case garnet has formed by reaction between pyroxene and feldspar and amphibole formation appears later than garnet formation.

The following sequences of corona minerals have been noted in the olivine-bearing coronites of Bankura :—

olivine—rhombic pyroxene (either only hypersthene or hypersthene followed by enstatite or a hypersthene-enstatite assemblage)—amphibole-garnet-feldspar, with small grains of green spinel within the amphibole aggregates :

olivine—hypersthene—secondary feldspar—garnet.

Where amphibole has developed it has done so at the expense of the plagioclase and the sequence is: olivine—hypersthene—hornblende—garnet with relics of secondary feldspar and small patches of hornblende. The amphibole has small green spinels. A second corona of amphibole after plagioclase has also been found. The granules of rhombic pyroxene are more or less amphibolized near their outer margins. Where compact, the amphibole has sharp border against the pyroxene but towards the garnet its outline is irregular with inclusions of feldspars. A discontinuous zone of feldspar intervenes between the amphibole and the garnet rims. Spinel formation is seen in the zone of rhombic pyroxene. Both green and brown mica as also muscovite are found associated with amphibole. In one specimen the olivine has been completely replaced by biotite. Apatite of late origin occurs in plenty. The olivine appears to be a highly magnesian variety as its optic axial angle was found to be 81°+, and is serpentinized to a small extent. The formation of all the zones in the three- or four- ply coronas was not a continuous process, and under varying conditions of pressure, temperature and water-content, formation of garnet and amphibole with mica followed the formation of rhombic pyroxene.

In the feldspars of these rocks, apart from the minute dots which cause the clouding, there are inclusions of pyroxene and amphibole, and biotite which increase in size and number towards their sources of supply. There is no doubt about migration of ions of these secondary minerals through the medium of pore fluids into the feldspars at the time of their formation outside the feldspars, as has been suggested by Poldervaart and Gilkey (1954, p. 89). The smaller feldspars surrounding the larger ones are unclouded but contain the inclusions. The feldspars have well developed albite-Carlsbad twins as also acline twinning. Bronzite is also much schillerized.

The granulitic norites show a granoblastic aggregate of plagioclase and pyroxenes, both rhombic and monoclinic, with small grains of magnetite. Hypersthene is not seen in all and seems to be secondary. Garnet is found in some. Some of the dykes are very fine-grained. The texture and granulitization appear to be metamorphic in origin. The rocks show more or less amphibolization. With the increase of the quantity of amphibole and decrease of feldspar, the rocks pass into hornblende schists or amphibolites. Amphibolization has proceeded along the cleavage cracks of feldspars producing weed texture and finally passing into an amphibole with sieve texture. A little quartz is also seen in some rocks. Epidotization has affected all the rocks more or less.

ORIGIN AND EMPLACEMENT OF THE BENGAL ANORTHOSITE

From the wide prevalence of anorthositic rocks containing a small amount of ferromagnesian minerals and the rarity of the anorthositic gabbros, it may be inferred that the original magma was anorthositic-gabbro in composition. The magmatic origin of the rocks is indicated by the relict ophitic texture, the nature of the primary ferromagnesian minerals such as bronzite, enstatite, diallage, ilmenite and titaniferous magnetite, the prevalence of C-twins (Gorai, 1951 and 1953), the igneous lamination, etc.

The nature of the outcrop of the anorthosite body and the general parallelism of the strike of the major joints and lineation with the strike of the foliation of the older gneisses which surround it, show that it was intruded as an elongated sheet-like mass into the gneisses. The dykes of anorthosite away from the main mass have the same trend. In view of the occurrence of anorthosite outcrops outside the main mass, it would seem that it has widened in depth and may have the form of a tilted laccolith. One noteworthy feature is that the 010 faces of the feldspars in the rocks with platy parallelism are often vertical indicating a vertical direction of movement. From the fact that porphyritic anorthosites with a non-directional texture are more prevalent, it seems that the rocks were formed mostly by the accumulation of plagioclase crystals and the smaller crystals which surround the larger ones might have been precipitated from the "interprecipitate liquid" (Wager and Deer, 1939, p. 127). Linear and planer parallelism was developed in those parts of the mass which were subjected to lateral pressure and where flow movements had taken place. In these respects there is similarity with the mode of origin suggested by Wells and Baker for the anorthosites of the Colony complex (1956, p. 150).

During subsequent metamorphism under granulite facies conditions there was reconstitution of the pyroxenes into granulitic aggregates of diopside and hypersthene, formation of garnet in coronas round magnetite and olivine, as also in isolated patches in the anorthosites, and clouding of the feldspars. The rocks were then subjected to amphibolite facies conditions. Later cataclastic and hydrothermal metamorphism followed with the formation of the epidote group of minerals, chloritization, scapolitization, and formation of myrmekite. Hsu (1955) has suggested the use of the term polymetamorphism for rocks having complicated metamorphic history with long intervals in between two or three types of metamorphism.

The author had shown previously that the anorthosite and anorthosite gabbros of Mayurbhanj in Orissa are of igneous origin. Prof. Buddington had referred to the presence of C-twins in plagioclase and pyroxenes with lamellar intergrowths in these rocks as evidence in favour of a magmatic origin (1957). In a preliminary study of the anorthosites of Kalahandi district of Orissa, the author has found C-twins and pyroxenes with lamellar intergrowth of diopside and hypersthene. Subramaniam thinks that the Sittampundi meta-anorthosites were originally igneous, in support of which he has brought forward many evidences (1956). The anorthosite-gabbro mass at Kadavur is also considered by him as igneous in origin (1956). Anorthosite has also been described from Rambha near Chilka Lake by Chandra (1955) and from near Koraput by Bose and near magnetite deposit of Biwabathan in Palamau district by Verma.* It would appear that anorthosites, once thought to be a rare rock in India, are widely prevalent in the Charnockite region of India, and were originally igneous.

Gentlemen, I thank you for giving me a patient hearing.

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SECTION OF BOTANY

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PRESIDENTIAL ADDRESS

ENVIRONMENT, ADAPTATION AND PLANT DISTRIBUTION

I am thankful to the members of the sectional committee of Botany for giving me the honour and opportunity to express some of my thoughts before this learned assembly. It was in the year 1942 that Bor (1942) addressed this section on "Ecology: theory and practice". Now, I stand today to examine some of the fundamental aspects of the subject in the light of recent work.

To the casual observer plants are distributed in the most haphazard manner in any locality. Ecologists struggling to find scientific order in the chaos sometimes relapse into this first impression on account of the complexity of the situation created by a large number of varied environmental factors and reactions of plants to them. Thus it is not surprising to find occasionally the expression 'chance distribution' in literature due to despair. The plant geographer dealing with large areas and distinct climatic conditions sails clear of the confusion, for his plants do or do not occur in the regions of study. The ecologist working most often in small areas is also safe as long as the plant habitats are broad based and well defined. Difficulties with the latter arise in offering explanation for peculiar behaviour of plants in close associations. I feel that investigations into the environment and adaptation will ultimately solve most of the problems of distribution.

ENVIRONMENT

The term 'environment' is related to the parts of an organism, the whole of it, the species or the community depending upon the unit of study. It finds its highest expression in the eco-system (Tansley, 1935) with circulation of materials and energy transference between plants, animals and their surroundings both physical and biological. There is a galaxy of factors each with limits of temporal and spatial variations (Daubenmire, 1947) and these combine and interact in an unlimited manner. Hence it becomes difficult to comprehend the environment as a whole from its components and we search for the critical or controlling factor for the time being.

Individual plants grow in one or more of the media of soil, water and atmosphere, and temperature seems to be of universal importance as it regulates metabolism (Misra and Puri, 1954) and physicochemical conditions of the environment (Odum, 1953). Periodicity in plants, such as sequence of dormancy, germination and sprouting of buds, leaf fall, flowering and fruiting, seems to be largely controlled by temperature in combination with photoperiod. In our country a rise in the average temperature in April leads to growth activation of most of the plants, but this is slowed down later by drought. After rains in July while the temperature is still favourable, the maximum growth of both annuals and perennials is observed. It is again the diurnal extremes of temperature obtained in September and October which revitalise the plants and make germination of winter annual seeds possible (Misra, 1958). The lowering of temperature in December and January slows down vegetative growth of most of the perennials. Thus the flushes of growth correspond to temperature fluctuations in nature. The six 'Ritus' described in Indian literature have some bearing in this context. The low temperature obtained on the Himalayas is responsible for the altitudinal zonation of plants.

The role of soil temperature in absorption of water and minerals is well known but its effect on the solubility of salts and gases and chemical reactions within the medium has not been sufficiently appreciated in relation to plant life. Puri (1950) has shown that there is an increase in the calcium content of river water in winter as the low temperature during this period promotes its leaching from the soil. Though the deeper layers of the soil are insulated against rapid variations of temperature, the exposed surface is subjected to wider fluctuations than either air or water, where there is intermingling due to convection currents. The latter medium is, however, more thermostable than air on account of its high latent heat. This may explain extensive geographical distribution of aquatic plants. There are thermal stratification and consequent seasonal circulation of lake water in temperate Himalayan regions which create special conditions for plant growth.

Rainfall is the second most important factor, as it regulates the supply of water to plants. It has a monsoonic pattern in this country, and its periodicity and intensity are of great significance to most of the shallow rooted annual plants of the rainy season. Drainage and water conservation conditions related to site and soil modify the situation for the plants. Steep slopes with thin soil are likely to remain dry for the most part of the year in spite of a heavy rainfall. However, the periodic gain and loss of water in a terrain are likely to yield good correlation with the distribution of types of vegetation. Therefore, in order to account for the loss, attempts have been made by a number of workers to assess the magnitude of evaporation and transpiration. In absence of evapotranspiration measurements these have been worked out from other meteorological data such as temperature, pressure, humidity, etc., by means of formulae derived from these elements by Koppen (1931), Thornthwaite (1933), Raman and Satakopan (1934). The effective precipitation is expressed as precipitation/evaporation ratios or indices (Thornthwaite, 1948).

Went (1957) has shown that the frequency of rainfall has a direct effect upon the growth of some plants in contrast to its general effect of humidity and moisture supply via soil. Tamm (1953), while studying the distribution of mosses on the forest floor, has drawn attention towards foliage leachings from above due to rainfall. If such leaching is common, the removal of salts from the young foliage periodically, may affect the growth and distribution of tree seedlings. Failure of teak plantations, in spite of adequate moisture supply by irrigation in the middle east countries, may be attributed to very low rainfall in the area necessary for the foliage leaching. It is difficult to have full appraisal of this phenomenon in nature unless a large body of data is built up from experiments with phytotron, wherein alone the environment can be effectively controlled. Equally interesting is the case of saline soils and some plants in desert areas which can absorb moisture from humid air in cool nights (Evenari and Koller, 1955).

Photoperiod and light intensity are recognised as important factors of the environment for germination, growth and periodicity. However, their interaction with temperature and mineral nutrition is not largely understood. Misra and Ramakrishnan (1959) have shown that light intensity and soil nitrogen are antagonistically related in the distribution of *Peristrophe bicalyculata* Nees.

Both the quality and intensity of light are affected during its penetration in water depending upon the turbidity, inorganic and organic solutes and depth. Pearsall and Ullyot (1934) and Misra (1937) found that 3 per cent of the surface intensity, which is the minimum for the growth of aquatic plants, reached at depths of 3 to 11 meters in different lakes of England.

Wind alters temperature and other atmospheric conditions. Dust and salt raised up by it cause mechanical injury to growing buds by abrasion. Whitehead (1956) has shown that wind at high radiation level may affect the growth and form of *Cerastrium tetrandrum* Curt.

Edaphic factors are responsible for the supply of moisture and salts to the plant. They also constitute the environment for the underground parts and soil biota. The soil complex has been represented by Misra and Puri (1954) as mineral, organic, biotic, solution and gaseous systems. Each of these, is of great significance to plant life. Misra (1938) has shown that rooted aquatic plants also depend upon the factors existing in the mud. Here reducing conditions obtain in which ammonia in place of nitrates, sulphides for sulphates, ferrous for ferric and other reduced ions for oxidised ones are released in contrast to oxidising conditions of aerated soils. These conditions have been measured in terms of rH values (Misra, 1938) or redox potential (Pearsall, 1938). The system also exchanges the ions with the water above. Such exchange relationships and redox potential together with the nature of the organic matter, in terms of C/N ratio, constitute a very different soil environment as compared with the terrestrial habitat. A reversal of the conditions from reducing to oxidising and from higher to lower pH value is obtained on exposure of the mud on drying of seasonal ponds (Misra, 1946). Thus the subaqueous, the marsh and the drying muds all present very different habitats for plant growth, and transition from one to the other demands great physiological adjustments on the part of the plants.

The individual soil factors and their interactions produce a mosaic of different edaphic situations in any area. Bhatia (1954) thus defined soil patterns in relation to pH, pore space, moisture, exchangeable bases, organic matter, nitrogen and calcium contents, in order to explain plant distribution in mixed deciduous forests of Madhya Pradesh. Upadhyaya (1955) has shown that annual litter production in our forests is much higher and in the grasslands much lower as compared to that of the temperate regions and that the organic increment in forests is received in March-April with maximum rate of decomposition during the monsoon period and in grassland soils it is added and incorporated in October—November. By Foliar and soil analyses Puri (1951) has shown different influences upon the soil of the litter of different species. The characters of some natural soils in contrast to those of cultivated soils are discussed by Misra (1954-55).

The biotic factors not only disturb the physical surroundings but also affect plant life directly. The latter effects have been considered in terms of disjunctive and conjunctive symbiosis by McDougall (1918). These include association of species, pollination, dispersal, competition, feeding and grazing, parasitism, mutualism, mycorrhizae and commensalism. The different aspects have been studied in many plant communities.

The multiplicity of factors and their interactions produce a large variety of habitats for plant growth, which is conditioned by temporal variations in their elements during the ontogenic phases of the plant. The requirements for seed germination, seedling and vegetative growth, flowering, fruiting, etc., are different, and these are derived from the ever changing intensities of the factors. The rates of change, the duration of particular intensities and the maximum and the minimum values of the factors are ecologically important in the habitat. Delayed effects of the environment upon plant growth and transmitted influences on account of exposure of one plant part upon another make us consider its past and spatial variations respectively. The study of the micro-climate is assuming significance in this context.

ADAPTATION

The cause and the effect are the basic elements of philosophy and when these are applied to structure, function and behaviour of plant organisations, we begin seeing adjustments between the latter and the environment. Whether these adjustments are ontogenic or of evolutionary nature, they are recognised as adaptations. Our conclusions, however, must be based on observational and experimental data free from teleologic or anthropomorphic explanations.

Every species has a range of tolerance towards the habitat. For instance, *Ipomoea reptans* Poir. grows right from the water to the dry margin of a pond. The same individual may show thin and large leaves and short green roots emerging from a spongy and elongated stem in adaptation to water and thicker and smaller leaves with extensive brown roots on a short solid stem in adaptation to xeric conditions. Examples of heterophylly and varying members of a clone also demonstrate the same phenomenon. These plants show a very wide range of tolerance towards moisture content of the habitat with a correspondingly wide range of structures. The physiological tolerance range may not be accompanied by structural adaptations in many plants. However, in both the cases ontogenic plasticity is responsible for meeting the ever changing intensities of the factors. When the form variations of this type are shown by populations of the same species in each habitat, these are called ecads (Clements, 1905). The same idea is expressed by the term 'ecophene' coined by Turesson (1922).

Echinochloa colona Link. covers the same range of habitat moisture as *Ipomoea reptans* Poir., but by separate populations of two morphologically distinct and interbreeding biotypes of the former of which one is adapted to marsh and the other to dry soil (Ramakrishnan, 1958). These are 'ecotypes' genetically differentiated and adapted to the habitat. Both these ecotypes possess ecads adapted to intermediate moisture levels within the tolerance range of each biotype. These facts can be demonstrated by culture experiments following the technique of Clausen *et al.* (1940). The mechanism of tolerance in the total species is thus shared by somatic as well as genic plasticity.

The same range of tolerance is, therefore, covered by one or many biotypes. In the case of *Ipomoea reptans* Poir. the biotype is adapted to a wide range which tapers in *Echinochloa colona* Link. with regard to habitat moisture, depending upon the number of biotypes within the species complex. The overlapping areas of the habitat-ranges for different species ultimately give rise to a mixture of populations which we call a plant community adapted to the habitat. This concept of the community is helpful in solving many problems of its floristic structure.

Environmental selection is definitely at work in sorting out suitable beings with 'niche' for each within the community-habitat complex. The community is thus carved out of a system full of potential forms, which are being thrown out in time and space by the interplay of genes each endowed with its own tolerance, form and function. This, in brief, appears to be the main mechanism of adaptation, whereby organisms utilise the earth's resources ever more efficiently.

Do plants get adapted to intensities of factors beyond the normal range of tolerance during their life time? The answer seems to be in the affirmative at least up to a limited extent, such as is evidenced by development of drought and cold resistance in some plants, upon gradual exposure to these conditions. Parija and Mallik (1936) have shown that the thickness of cuticle in leaf increases with drought and light intensity and Parija (1931) has explained adaptations by his law of modifications as enunciated in the words: "If an organism, an organ or even a cell is subjected to a stress, physical or chemical, the organism, the organ or the cell changes in such a way that the effect of the imposed stress is nullified." The phenomenon assumes significance in ecological adaptation to climatic conditions or acclimatization which extends the amplitude of the species. Hence the gradual and abrupt changes in factor intensity of the environment have to be reckoned, in interpreting plant populations.

DISTRIBUTION OF PLANTS

With the background developed on the problems of environment and adaptation, it is now possible to have an appraisal of the ecological distribution of plants. The dispersal of diaspores and their germination and growth initiate a series of plant processes involving trial and establishment of species. Aggregation of individuals leading to competition between them and ecesis result in migration to newer areas and invasion of other plant communities in the environmental flux. Thus, at any moment, we get plant populations and individuals most suited or adapted to the ecosystem.

Aquatic plants are held to be most widely distributed. None the less, they are as sensitive to habitat conditions as any other group of plants. Misra (1938) has shown by culture experiments conducted both in the lake and the laboratory and by chemical analyses of plants and soils, the dependence of water plants upon the nature of the substratum. Thus, coarse and sandy bottom is colonised by *Littorella uniflora* Aschers. and *Lobelia dortmanna* L. and as peat accumulates they are succeeded by *Phragmites communis* Trin. in the English lakes. In silted areas the fine inorganic mud bears *Isoetes lacustris* L. and with the accumulation of well decomposed humus in it *Potamogeton* spp., waterlilies and sedges follow in succession. The rate of decomposition of organic matter under anaerobic condition seems to be the most important event of the habitat. It is rapid with the release of bases in heavily silting areas, but is slowed down on sand resulting into peat accumulation. There is a decrease of calcium and potassium and increase of iron and aluminium with the exchange of bases in the organic mud and these have profound specific effect upon the nutritional balance of the plants.

The distribution of marsh plants is largely controlled by the edaphic factors. Seasonal marshes and lowlying lands with wet and dry phases have an interesting assortment of plant species. The subaqueous reducing conditions and their conversion into oxidising conditions upon exposure of the mud has already been discussed. Plants like *Echinochloa colona* Link., *Alternanthera sessilis* Br., *Marsilia erosa* Willd.. etc. get adjusted to such drastic changes, whereas others will grow either in the aquatic phase or on the dry mud.

The distribution of many plants of the dry phase of the lowlying lands is controlled by natural processing of their seeds. The seeds of *Polygonum plebejum* Br., *Heliotropium indicum* L. and a few others would not germinate unless they remain embedded in wet mud for a few months as shown by Mall (1955). This author has also shown that diurnal fluctuations of temperature as obtained in September-October are necessary to induce germination in seeds of many cold season annuals distributed in the habitat. Went (1957) has given several examples of natural processing of seeds such as by rainfall, temperature, etc. before they can germinate. In fact the entire life cycle of most of such plants is synchronised with the seasonal conditions of the habitat. In case of *Xanthium strumarium* L. Kaul and Misra (1957) have discovered the monsoon and the post monsoon strains of the plant in relation to photo-period so that stands can be found throughout the year in suitable localities.

When the distribution of plants in relation to edaphic factors is worked out very diverse mechanisms of adjustment are revealed. In relation to soil calcium, Misra and Siva Rao (1948) showed that the caliphytic ecotype of *Lindenbergia polyantha* Royle is capable of accumulating calcium in its tissues in proportion to the soil exchangeable calcium. Rorison, as quoted by Whitehead (1957), discovered that *Scabiosa columbaria* Tring. grew in Britain as a calciphyte on account of a higher pH of the substratum, which immobilised the toxic ions of aluminium. Bhatia (1956) visualised an interaction of calcium and phosphorous both in the soil and the plant in case of *Tectona grandis* L.f. distributed in Madhya Pradesh. Tansley (1917) demonstrated the non-calciphytic nature of *Galium sexatile* L. in its susceptibility to shoot competition with *G. sylvestre* Poll. in calcareous soils. Salisbury (1920) argued that a number of species take to calciphytic habit on account of other biotic factors working against them on non-calcareous soils. The same phenomenon has been revealed by Sharma (1953) in case of *Sida acuta* Burm. distributed on lime rich soil and by Bakshi (1949) in case of *Anisochilus eriocephalus* Benth. found growing on tiled housetops in the rainy season. Ramakrishnan (1959) has demonstrated calciphytic and non-calciphytic biotypes in *Euphorbia thymifolia* L. wherein root competition and germination behaviour segregate the two habitat types.

Bharucha and Dubash (1951) have studied the problem of nitrophily in relation to ruderal plants of Bombay. Several grades of nitrophily from tolerance of high nitrate concentration in plant tissues to limited absorption of the salt from the substratum, have been described. Misra and Ramakrishnan (1959) have shown an interaction between light intensity and soil nitrate upon the germination of seeds and growth of *Peristrophe bicalyculata* Nees. so that the plant gets distributed in nature in exposed habitat with low-nitrate and shaded areas with high-nitrate. Nitrogen assimilation is somehow higher in shade in this plant.

The distribution of plants in relation to trace elements in the soil is being worked out by Iyer and Satyanarayan (1958) at Bombay. All such studies and the preceding examples are enough to prove that there are varieties of mechanism working in the distribution of plants in relation to chemical characters of the soil.

Many plants seem to be distributed in relation to the physical characters of the soil. Its porosity, for instance, is important for the incidence of *Argemone mexicana* L., *Cassia tora* W. and A., *Tridax procumbens* L., etc. on disturbed soil such as dug up and deposited earth which possess high non-capillary porosity. Erosion of soil similarly promotes the growth of such plants as are capable of propagation from the exposed roots. *Carissa spinarum* L. (Misra and Joshi, 1952) on the hills and *Capparis sepiaria* L. (Misra, 1944) on old river alluvia are common examples among many others. *Zizyphus rotundifolia* Lamk. on the foot of hills, goes on flourishing with the deposition of soil from above. *Syzygium heyneanum* Wall. is found perched along river-cut precipice. *Enicostema littorale* Bl. and *Heteropogon contortus* Roem. et Schult. are characteristic plants of well drained soils. Sedges, *Ischaemum rugosum* Salisb., etc. are more aggressive on waterlogged soils as compared to their associates on drier substrata.

Leaving aside altitudinal zonation of plants, the types of vegetation correspond roughly with the amount of rainfall in tropical and subtropical regions of India. The evergreen and the semievergreen forests are confined to the wet zone with more than 200 cm. of annual precipitation. In Madhya Pradesh *Shorea robusta* Gaertn. f. forests are confined to 100-200 cm. rainfall region in the North-East and the East. Dry deciduous and savannah forests lie within 50-100 cm. rainfall areas of Karnatak, North-West Deccan, Upper Ganges and Upper Punjab plains. The arid zone with less than 50 cm. of rain is characterised by thorn scrub jungle and desert. However, detailed distributional analysis of the climatic types on floristic basis does not fit in closely with the rainfall gradient alone as much of the water is lost by drainage and evaporation. Hence, attempts have been made to obtain better index for moisture conditions in physiographically uniform regions by taking into account evaporation data and by calculating effective precipitation as precipitation/evaporation ratio or index (Thornthwaite, 1948). Bharucha and Shanbhag (1957) derived mean monthly evaporation figures of 104 stations in India, Pakistan and Burma following Raman and Satakopan (1934), from other meteorological data such as temperature, humidity, pressure, etc., since direct readings of evaporation were not available for all the places. The monthly effective precipitation calculated by these authors followed the climatic types given by Champion (1936) for those regions.

A word of caution is necessary against the generalisation given above. The indices meant to designate the climate as influencing plant distribution, will not hold good for all the plants distributed in an area. While the dominant form of vegetation or even the dominant species may reflect the local climate, the subordinate species may be distributed in relation to microclimate. The growth form, the life cycle and the ecological amplitude of the species are to be considered in relation to the periodicity of the climatic factors. A single factor like rainfall can be relevant with regard to the distribution of shallow rooted monsoon annual species within an area of uniform soil and temperature (Misra and Das, 1959).

Explaining the distributional behaviour of *Petrocarpus marsupium* Roxb. in Madhya Pradesh, Hewetson (as quoted by Bhatia, 1956), visualises very little possibility of finding any extensive stand of the tree. The reasons advanced are that there must be rains throughout the month of May to enable the seeds to germinate and it must be a good seed year for the tree ; the former may happen twice in a century and the latter at intervals of five years and the two may coincide only once in 100,000 years !

Frost can easily keep out a number of plants from exposed habitats which are otherwise suitable for their growth. *Shorea robusta* Gaertn. f. is able to spread in such regions only under cover of plants. Raghavan Nair (1957) has shown that *Cytisus scoparius* Link. provides a suitable cover for the 'shola' species on the Nilgiris.

The distribution of plants is regulated to a very large extent by biotic factors. Interspecific competition aided by priority in succession is responsible for the development of a characteristic flora of the plant community. This competition may be interfered by the activities of man and animals. Destruction of the natural vegetation leaves open areas for the invasion of alien plants. A large number of foreign weeds are thus flourishing in our country, e.g. *Croton sparsiflorus* Morung. along highways, *Argemone mexicana* L. and *Euphorbia dracunculoides* Lamk. as weeds of cultivated areas.

The distribution of climatic climax forests in our country has been much disturbed by men. Historical account of the same is given by Misra and Puri (1954). The earlier stages of regression can be seen along the fringes of the forests. In northern plains of the country those nearer the villages are reduced to open scrub jungles of *Butea monosperma* O. Ktze, *Acacia leucophloea* Willd., *A. arabica* Willd., *Zizyphus* bushes etc. (Misra, 1957). In the last stage the village trees are (a) those which survive the intense biotic pressure like *Holoptelia integrifolia* Planch., *Streblus asper* Lour., *Phoenix sylvestris* Roxb., etc., (b) those which are tolerated for one reason or another like *Madhuca latifolia* Macbr., *Ficus religiosa* L., *Melio azadirachta* L., *Tamarindus indica* L., etc. and (c) those which are cultivated like *Mangifera indica* L., *Psidium guyava* L., etc.

Tectona grandis L. f. gets eliminated from most of the forests of Madhya Pradesh on account of intensive biotic disturbances (Misra and Joshi, 1952). With a little protection it can flourish even inside a forest of *Shorea robusta* Gaertn. f. (Tiwari, 1954). Sharma (1955) showed that up to 95% of the seeds of *Boswellia serrata* Roxb. were destroyed by chalcids and rodents on the forest floor and not more than 3 or 4 seedlings per acre were able to get established. In Khandwa he recorded 100% mortality of the seedlings due to interspecific competition and browsing. Saplings suffered from ravages of pigs eating up the fleshy roots and of termites working up through the roots to the pith of the stem. Porcupines attack the adult trees. Hence the odds, on account of biotic factors, are too many against the distribution of the tree.

Now all the ecologists agree that apart from the high Himalayan meadows, there is no climatic climax of a grassland in India. The extensive grasslands of Assam and the Nilgiris appeared as a result of destruction of the primeval forests in prehistoric times. The present character of the soil and the microclimate are now so altered that there is no possibility of the forest trees reappearing in the areas unless they are aided by man. The Savannahs and the rolling monsoon grasslands as fillings in forest areas are the products of fire, grazing and other biotic activities, which are continuously operating and maintaining the degenerated vegetation.

A study of the bioecology of the grasslands of Madhya Pradesh revealed to Tiwari (1955) a wide flux in the floristics on account of response, reaction and coaction (Clements and Shelford, 1939) in the biome. He has traced the distribution of five bioseral associations, viz. (a) *Themeda-Cymbopogon* on low hillocks and valleys of Deccan trap, (b) *Apluda-Chrysopogon* in partly shaded areas of southern part of Madhya Pradesh, (c) *Iseilema-Heteropogon* on grazed hill tops and slopes, (d) *Dichanthium-Bothriochloa* on deeper soil in valleys and foot of hills exposed to moderate grazing, mowing and fire, and (e) *Andropogon-Eragrostis* on areas open to overgrazing and erosion. Pandeya (1953) has assessed the relative intensity of grazing in the grasslands by a study of their biological spectra.

EXPERIMENTAL ECOLOGY

The preceding discussion on environment, adaptation and plant distribution has sufficiently shown the importance of experimental approach towards the solution of ecological problems. Whether we study the community in order to solve autecological problems or indeed solve them in order to understand the vegetation, I submit that for achieving these the experimental method is the only scientific tool at our disposal. As Whitehead (1957) has put it, description of a problem is not its solution nor demonstration of correlation is a proof that the factor concerned is causal. Problems formulated on field observations have to be clarified at various levels of refinement in the laboratory and the garden.

Let us take the problem of the ecological distribution of *Polygonum plebejum* Br. It is found in abundance on the dry bed of ponds though it may occur rarely on ordinary soil as well. The plant shows, in addition, tremendous form-variation. Now how shall we work out its behaviour? The first step would be experimental cultivation. Transplant experiments following Turrill and Marsden-Jones (1930) and Clements *et al.* (1950) show that the species can grow well on almost any type of soil and the form variations are produced in response to both moisture conditions and varietal differences. When the seeds are sown at different intervals after collection they fail to germinate unless these are stored in mud under water for two to four months. The experimental technique thus yields a plausible explanation for the high incidence of the plant in dry pond beds. Its sporadic occurrence in other habitats can be explained by assuming casual dispersal of the mud-processed seeds from the pond bed, for, any soil is good enough for their germination and further growth and development. When the same technique is adopted to work out the distribution of the green form of *Euphorbia thymifolia* L. it is found that the plant succumbs to root competition on lime rich substrata (see p. 6). Thus, experimental cultivation is of as great importance to the study of plant ecology as, according to Heslop-Harrison (1953), it is for plant taxonomy.

In the experiments cited above the temperature was not controlled. By processing the seeds at different temperatures Mall (1955) was able to show that diurnal fluctuations in this factor, as naturally obtained in the months of September and October, are quite important in inducing germination ; and this finding would further explain the seasonal behaviour of the plant. Went (1957) has been able to control effectively the various factors of the environment in his phytotron and has thereby demonstrated how conditions of germination control the distribution of many plants in nature.

An effective control of the plant environment has enabled a number of workers to probe deeply into the behaviour of plants with regard to growth and distribution (Hudson, 1957). Their findings indicate that conditions of temperature, light and rain are the most important in this respect. Nyctotemperature and thermoperiodicity have been shown by Went (1957) to limit the geographical and altitudinal distribution of many plants. Further, he found that soil temperature is not as important as generally assumed. It has also been demonstrated that the requirements of seed germination, seedling growth and growth and development of the adult plant are different and sometimes even antagonistic for the different phases.

Along with the culture work a chemical analysis of the plant is very often found useful in explaining its tolerance of environmental conditions. The examples cited in the earlier section have abundantly revealed the extent of absorption and assimilation of soil calcium and nitrogen by different plants under divergent situations.

CONCLUSION

I have tried to place before you, with the help of examples mostly worked out in this country, the meaning of environment and adaptation and its bearing on plant distribution. The relevance of experimental methods in the study of ecology has been abundantly justified. The problems in the follow up turn out to be complex demanding a high degree of skill from various disciplines of science. We begin with the plants in the field and then take them to the garden and the laboratory just to return to the field with some working hypothesis explaining their behaviour. None the less, the problems are always formulated around the environment, adaptation and distribution whether it be autecological or synecological study involving community organisation and succession.

In this country we have been busy for long in describing the vegetation and in applying ecological concepts to it which were developed in other countries. It appears to me that an experimental analysis of our own materials will be more rewarding. Facilities for the same are not adequate at our working centres. When at Varanasi we turned our attention to the photoperiodic and thermoperiodic behaviour of *Xanthium strumarium* L. in relation to its distribution we could not control the relevant environmental factors to the extent demanded by modern researches. Nor we could obtain seeds, plants and soils from different parts of the country for proceeding with the cultivation work. Most of the working centres are handicapped in the same way and our need is to have a chain of field stations in different climatic zones and a few laboratories equipped with Went's (1957) phytotron or what Clapham (1956) calls an ecological machine. It has a series of rooms with effective control over temperature, light, atmospheric conditions, precipitation and culture nutrients, wherein plants can be grown and tested under any combination of factors desired. It may not be possible for us to afford for plant research laboratories of the magnitude of Earhart laboratory and Clark greenhouses situated at the California Institute of Technology but we can surely have smaller units. There is an opportunity for our country to take lead in this matter as none of the like exists anywhere in the tropical regions of the world.

The works of Bonnier (1874), Turesson (1922), Marsden-Jones and Turrill (1930), Clausen *et al*. (1940) and Clements *et al*. (1950) among many others should leave no doubt about the urgency of establishing a chain of field stations where plants can be grown at different altitudes and on regional soils under the respective climatic conditions. This will facilitate our taxonomic and ecological investigations on experimental basis. It is possible to institute a board on the lines of Nature Conservancy of Britain to coordinate such facilities available with the universities, research institutes, the Botanical Survey, agriculture, forest and horticulture departments, national parks, etc.

I close this address in the hope that ecological studies in India will soon get reorientated on experimental lines.

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SECTION OF ZOOLOGY AND ENTOMOLOGY

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PRESIDENTIAL ADDRESS

INLAND FISHERIES OF INDIA AND THEIR PROBLEMS

One of the vital and urgent problems facing our country today is the problem of food production. Although India has vast resources, the present rate of food production is inadequate to meet the needs of the alarmingly increasing population of the country. In fact, this subject is considered the core of our national planning and highest priority is given to achieve self-sufficiency in food production in as quick a time as possible. It needs no emphasis that in this programme, the production of protective food occupies a high place. It is well-known that fish affords highly nutritive food and for this reason several advanced countries have adopted fish as one of their main items of food. Majority of our people suffer from malnutrition. Potentially India is a very rich fishery country but we are backward in regard to fish production. In order to meet the protein requirement of our people it is imperative to develop and exploit the latent fishery resources. I would, therefore, wish to speak to you today on some aspects of fisheries in India. I shall confine myself to a brief treatment of inland fisheries and their problems, a subject with which I am closely associated for the last several years.

Introduction

The inland fisheries resources of India are vast and varied. There are extensive river systems all over the country with a vast net-work of irrigation canals, reservoirs and tanks. There are in some areas large number of ponds, *bheels* and swamps. There are also vast brackishwater lakes and extensive estuaries. In addition to these water resources in plains there are in the Himalayan region and some parts of South India a number of lakes and hill streams at high altitudes. All these waters support a variety of good species of fishes. Potentially the inland fishery resources of India are among the richest in the world but adequate attention has not been paid so far to develop them. There are practically no conservation measures in force on capture fisheries of rivers, lakes and estuaries and the culture fishery operations in the impounded waters are either absent or not sufficiently well organised. Large masses of fertile cultivable waters are at present lying fallow. In spite of these, fish production from the inland fisheries of India is appreciable, indicating the richness of the fisheries. Even under the present backward condition of fisheries, India produces both from marine and inland waters a little over a million tons of fish per year and ranks eighth amongst the fishing nations of the world. There is no doubt that India could occupy a high place among the fishing nations if suitable measures are undertaken to organise the fishing industry. The two countries where inland fisheries occupy a significant position in their national economy are China and India. Unlike in other advanced countries, the magnitude of inland fisheries of China and India is considerable. It is generally believed that the production from inland waters in India is about ⅓rd the total production of fish. Since the inland fisheries are highly dispersed and since there is vast amount of subsistence fishing in rural areas, the production from inland waters perhaps is more than is estimated at present. The national income from inland fisheries is of a high order.

The inland fisheries in India have a significant and important role to play in the rural economy. Every village in the country has some water area and close to some of them are stretches of rivers and irrigation canals. If all the water resources in the country are fully developed and fish production stepped up, this important commodity will not only provide the much needed protein food to the vast rural population but also provide them with a subsidiary occupation which would give them an additional income. In this respect fish culture should be regarded as a cottage industry and every encouragement should be given to organise its development.

The present backward condition of the fisheries in India is due to many causes. During the pre-independence period there was little appreciation of the need for fisheries development and efforts made in this direction by various States were far from impressive. However, in recent years there has been a widespread recognition of the need for organising fisheries development both by the Central and the State Governments. A large number of research and development projects are being implemented under the Five-Year Plan programmes. The Central Ministry of Food and Agriculture has been taking active interest in this regard and a number of Fisheries Conferences sponsored recently by the Ministry have made suitable recommendations on all vital aspects of fisheries development. The Ministry of Community Development has also taken steps to organise fishery development in all their centres in various States.

In order to develop the fisheries of the country on sound lines it is essential to find proper solutions to many basic problems facing our fisheries. This entails extensive fisheries surveys and research. The Central Inland Fisheries Research Station established by the Government of India in 1947 and some of the State Fisheries Departments have for the past few years undertaken vigorous investigations of several problems relating to improved cultural techniques and conservation measures which have a direct bearing on development of inland fisheries. The Standing Fisheries Research Committee of Government of India periodically reviews and coordinates fisheries research carried out by various departments and Universities and makes suitable recommendations for implementation. India is a founder-member of the Indo-Pacific Fisheries Council, set up by the Food and Agricultural Organisation of the United Nations which takes active interest in the development of fisheries of South East Asian countries.

INLAND FISHERY RESOURCES AND THEIR PROBLEMS

The inland fishery resources of India can broadly be divided into Freshwater and Brackishwater Sections. The former includes the great river systems of India and the vast net-work of irrigation canals, tanks and reservoirs. In addition, there are in the deltaic areas innumerable ponds and *jheels*. The extensive river mouths and vast areas of lagoons and large number of *bheris* in the coastal regions constitute the brackish-water fisheries.

From the point of view of the type of management required for the development of the fisheries, they can be divided into Capture and Culture Fisheries. The management in regard to the fisheries of the rivers, estuaries and the large lakes is directed towards conservation and rational exploitation of the fisheries in order to maintain a sustained productivity in them, whereas, the fisheries in smaller impounded waters, such as tanks, *jheels* and ponds are governed by cultural operations relating to pond management.

CAPTURE FISHERIES

RIVERINE FISHERIES

The Sub-continent of India exhibits such wide contrasts in its geographical and climatic features, that the riverine resources are highly diversified in their nature. The extensive river systems of India can be broadly classified into the rivers of Northern India and the rivers of the Peninsular India. The rivers of Northern India comprise of the Ganga, the Brahmaputra and the Indus river systems originating in the Himalayas and flowing across the great alluvial plains bordered by the Himalayas on the North and the Vindhya and the Satpura ranges on the south. There is not any conspicuous fishery in the upper reaches of these rivers which have their sources in the ice-bound Himalayan range. It is only when the rivers flow down to the plains that they support a rich fishery. There is a great fluctuation in the volume of water in these rivers. The volume of water swells during the rainy season to nearly 300 times that of the summer flow. The river Ganga with its more important tributaries, the Kosi, the Gandak, the Burhi-Gandak, the Ghagra and the Gomti on its left flank and the Jamuna and the Sone on its right with a total length of over 5000 miles is one of the largest river systems of the world. The stretch of about 1000 miles of the Ganga from Hardwar to Lalgolaghat with numerous deep pools in the silt-covered sandy bed supports a rich fishery.

The Brahmaputra river system which is about 2,500 miles constitutes a rich fishery resource in North-Eastern part of India. As in the case of the Ganga it is only the part of Brahmaputra in the plains which supports a rich fishery. The Brahmaputra in Assam is less exploited than the river Ganga and there is immense scope for organising fishery development of this river. The Sutlej and the Beas of the Indus system constitute the riverine fisheries of the Punjab and the Himachal Pradesh.

The riverine fisheries of Northern India mainly consist of carps, catfishes and the Hilsa. The Major carps, *Labeo rohita, Cirrhina mrigala, Catla catla, Labeo calbasu* and other carps like *Labeo dyocheilus, Labeo bata, Cirrhina reba* and catfishes—*Mystus aor, Mystus seenghala, Silonia silondia, Wallago attu, Pangasius pangasius, Bagarius bagarius, Rita rita, Clupisoma garua, Eutropiichthys vacha, Ompak bimaculatus* are the common species in these waters. *Hilsa ilisha* forms a substantial fishery both in the Ganga and the Brahmaputra rivers.

In the Gangetic delta the major carps of the river system are widely used for culturing in the extensive impounded waters. Since these major carps do not breed in confined waters the larvae and fry of these fish are collected year after year from the rivers and utilised for stocking in the impounded waters. The collection and transport of spawn from the rivers is an ancient industry in this region. In recent years the spawn trade has increased enormously and fish seed is being supplied extensively to several States in India. A large number of spawn and fry collection centres have been located and organised in recent years. There is great scope for intensifying the collection of spawn from suitable areas. The fish seed resources of the Brahmaputra are at present under-developed but the Assam Government is making efforts to organise collection of fish seed from the Brahmaputra river system.

Associated with these riverine fisheries are large numbers of low-lying areas which are inundated during the flood period both along the Ganga and the Brahmaputra systems. These *jheels* and *bheels* in north Bihar, eastern Uttar Pradesh and Assam have good potentialities for fish production. There is, however, no scientific management of these fisheries at present. If they are rationally developed and exploited, fish production in such waters can be stepped up very considerably. The fisheries of the *bheels* and *jheels* consist of the river carps, catfishes, clupeids and also the marshy fish fauna comprising of *Channa* spp., *Heteropneustes fossilis, Clarias batrachus, Anabas testudineus, Mastacembalus* spp., *Notopterus* spp. and others. The respective State Governments should bring such waters into effective management.

The four river systems of the Peninsular India are the Mahanadi, the Godavari, the Krishna and the Cauvery which drain eastwards. The Mahanadi river drains a very large volume of water and has a rich fishery in the deltaic region. The lack of proper roads and difficult terrain of the river have made the rich fishing grounds and deep pools inaccessible during the greater part of the year with the result the Mahanadi is considerably under exploited. In the middle and lower reaches there is an abundance of fish of similar species composition as that of the Ganga in addition to a few peninsular forms. The *Hilsa* and the three major carps constitute the major fisheries in the lower reaches of the Mahanadi. The seed resources of the Mahanadi are adequately exploited at present to meet the requirements of Orissa State. The upper reaches of both the Krishna and the Godavari systems are also considerably poor in respect of fish. The deltaic regions are however quite rich in fish life and are subjected to adequate exploitation. Some stretches of the middle portions of the rivers though rich in fishery are practically unexploited because of the difficult terrain and rocky sub-strata. In addition to the endemic species of fishes and also *Catla* which is a naturalised fish in this drainage, *Labeo rohita* and *Cirrhina mrigala* introduced into the basin in recent years have been observed to be breeding in these river systems and are being caught in large quantities. The Godavari river system supports also a rich prawn fishery represented by *Palaemon carcinus* and *P. malcomsonii.* Fingerlings of *Catla catla* are caught in the paddy fields in the deltaic areas and are utilised for stocking purposes. In recent years efforts have been made to collect carp spawn in the Godavari delta. The Hilsa contributes a substantial fishery in the deltaic regions of the Godavari, Krishna and the Cauvery.

The Cauvery with its numerous rapids, gorges and waterfalls is considerably different from other river systems in India and it also exhibits substantial variation in its fish fauna. The upper reaches of Cauvery system supports two large sized Mahseers, *Tor khudree* and *Tor mussullah.* The main fishery of the river is composed of carps and catfishes but the species differ considerably from those of other river systems.

The only two large rivers which flow to the west and drain into the Arabian sea are the Narmada and the Tapti. These rivers abound in prime fish like the major carps, large and medium sized catfishes, Mahseers and the typical peninsular forms like *Labeo fimbriatus*, but the fishing industry as such is poorly organised and the fishery resources have not been tapped adequately in these rivers. In the lower reaches of the rivers and their estuaries, *Hilsa* form a substantial fishery.

Need for conservation of riverine fisheries

The main limiting factor in the rivers is the high fluctuation in the river flow which increases enormously during the flood season. The capacity of a river to support rich fish stocks is mostly determined by the availability of suitable shelters (pools) along the river bed, food organisms, suitable breeding grounds, natural nurseries for the young and other ecological factors. Often the man-induced hazards along the river course tend to alter these conditions to the detriment of the fish stocks. It is also observed that some parts of the rivers are subjected to over-exploitation. During certain seasons barriers are erected across the rivers in parts of the Ganga in Uttar Pradesh and in almost every peninsular river which serve to capture all sizes and species including brood fish and juveniles. In certain areas where the juvenile fish predominate they are extensively caught. In fact the present trend of fisheries seems to suggest that the exploitation in the rivers of the plains has been greatly intensified without any reference to the capacity and productivity of our rivers. There are, however, gorges, rapids and deep rocky pools in the hilly sections of the rivers which are inaccessible to the fishermen and which give natural protection to the fish stocks. But for such protection in the rivers, the riverine fisheries would have been completely depleted. There is at present no conservancy measure in force in any of these rivers. Even in States where fishery laws are in force, they are not effectively enforced. It is, therefore, very essential that necessary conservation measures such as prohibiting destructive methods of fishing, prohibition of capture of young and juvenile fish and also the brood fish and closure of fishing in sections of rivers and establishment of sanctuaries for providing protection for the spawning of fish should be enforced.

Introduction of suitable fishes in certain drainages

Some of the rivers in Peninsular India do not have quick growing and large sized food fishes. The yield of fish from these rivers is consequently poor although the water resource is rich. The introduction of the major carps into the peninsular rivers was attempted by the Madras Fisheries Department and as a result of their experiments *Catla* has successfully established itself in the Cauvery and the Godavari drainages. Similarly *Labeo rohita* and *Cirrhina mrigala* have also shown indications of breeding in the lower reaches of the Godavari. It is necessary to make further attempts to acclimatise suitable species of fishes all over India if the inland fishery resources are to be fully developed.

River pollution

With the rapid industrialisation of India and consequent establishment of large number of sugar factories, pulp and paper mills, breweries, distillaries, leather tanneries, textile mills, jute mills, saw mills, metal works, quinine, soda and other chemical factories, coal mine, oil refineries, cement factories, iron and steel factories and others, large quantities of factory wastes are being discharged into the river systems all over the country. The factory effluents adversely affect the fisheries for a considerable stretch of the river and also affect the migration of fishes in such polluted areas. Considerable work has been done to determine the effect of factory effluents and also the domestic sewage on the fisheries of such areas. It is very essential to protect the fisheries from such adverse effects. Adoption of suitable remedial measures such as diversion of effluents, dilution of the discharge rendering it innocuous before releasing in the stream, neutralisation of toxic substances etc. should be made obligatory on the part of industrial organisations. The concerned State Fisheries Departments should, with the cooperation of various industries, set up specific standards for a particular type of industry as to the control of pollution in rivers, which could be used as a guide for all future industries.

LACUSTRINE FISHERIES

There are a few natural lakes in the Himalayan region of Uttar Pradesh and Kashmir in the north and the Nilgiris in the south and also a few large swampy lakes in Manipur valley. The bulk of the lacustrine fisheries in India consists of large number of reservoirs constructed across river basins all over the country. High priority has been given in national planning in recent years for conservation of water resource resulting in the establishment of a number of multi-purpose river valley projects for flood control, irrigation and hydro-electric power production. The water-spread area in these reservoirs range from a few square miles to over 250 sq. miles. If fishery development is organised in all these reservoirs it would be possible to produce quite a large quantity of fish from these waters. There is a proposal for the development of fisheries under the Second Five-Year Plan in some of the major reservoirs such as Bhavanisagar, Malampuzha, Krishnagiri, Mangalam and Manimuthar. The project authorities of the Damodar Valley Corporation, the Hirakud and the Tungabhadra have already initiated fishery development programme in their respective reservoirs. The Bhakra Dam reservoir in the Punjab, the Mayurakshi project in West Bengal, the Chambal and Gandhisagar projects in Madhya Pradesh, the Jawai dam in Rajasthan and Rihand and Matatala dams in Uttar Pradesh are under construction and the respective State Governments propose to take suitable measures for the development of the fisheries in them. The Madras Fisheries Department has successfully developed the fisheries of the Mettur reservoir by extensive stocking and conservancy measures. Further, experiments carried out in deep water fishing have now led to full exploitation of the fisheries of the reservoir. On an average 400 tons of fish are harvested annually from the reservoir. The major fisheries constitute *Catla catla, Cirrhina cirrhosa, Mystus seenghala, M. aor, Silonia silondia,* and *Wallago attu.*

The Damodar Valley Corporation has undertaken extensive stocking of the Tilaiya reservoir with major carps for the last few years and the fishery of the reservoir has become quite productive. Exploitation of the reservoir is also being organised. There is a proposal to undertake fishery development in all the reservoirs of the Corporation. Since all the river valley projects are potentially rich fishery resources, the project authorities should take adequate steps to organise fishery development in them. The main items of work to be carried out in this connection are the removal of tree stumps in the area which will be submerged by the water of the reservoir to facilitate easy operation of fishing nets, extensive stocking of the reservoir for a number of years with suitable species of fishes and adoption of conservation measures to enable the fish to breed in the neighbouring areas which would bring about natural stocking of the reservoir in subsequent years. It is also necessary to colonise fishermen for conducting fishing operations around the reservoirs.

Dams and Fisheries

It is well known that construction of dams across rivers affect their fisheries considerably. The effects are mainly of two kinds, environmental and obstructional. Construction of dams forges a variety of changes in the environment of the fish populations and may adversely affect their balance if the environment alters beyond certain narrow limits. Dams and weirs also act as physical barriers to migrations of fishes and such obstructions, in the case of fish performing spawning migrations, may exterminate or seriously deplete its fishery by preventing the fish reaching its natural spawning grounds. Even in the case of fish which do not undertake spawning migrations, the restriction of the area of spatial distribution of populations by creation of artificial or ecological barriers may bring about adverse effects on their fisheries. Investigations elsewhere have revealed that while the construction of a dam is generally harmful to the fisheries, no obvious effects have been noticed in some cases and in yet a few cases beneficial effects have been reported. Hence before deciding on any measures to overcome the obstruction or providing environmental facilities it is essential to undertake detailed investigations on the behaviour of fish populations in the area.

One of the means of preventing obstruction for the migration of fish in other countries is to provide suitable passage in the form of fish ladders, fish passes and fish lifts in the dams. In India, however, the problem of providing fish passes in the dams is still a controversial subject and the types of fish passes designed and constructed in America, Canada and Scotland are unsuited to this country. Some fish passes constructed in the dams and weirs in the Punjab have not only proved to be ineffective but serve as fish traps. Nevertheless it is essential to investigate and devise a suitable fish passage which would be used by the species of fishes in particular drainages at a low cost especially in respect of the large number of tanks in peninsular India, which would ensure natural stocking of the tanks by fish migrating from below. Most of the high dams in India are erected in the middle or upper reaches of rivers and the adverse effects of such obstructions on the fish populations of the areas are not likely to be appreciable. Any damage done to the fisheries of the basin can be substantially alleviated by implementing such remedial measures as affording protection to the congregations of fish below the dam and stocking of the reservoir with suitable species of fishes.

The only fish of great commercial importance with long range migration is *Hilsa ilisha* which ascends the estuaries and rivers for breeding. Hilsa requires gradual gradient and deep waters to successfully negotiate upstreams and unlike Salmon, it cannot circumvent obstacles. While *Hilsa* is known to ascend not beyond about 50-70 miles from the sea in the peninsular rivers it ascends to a distance of over 800 miles up to Agra and forms a very rich fishery in the Ganga. Similarly the Hilsa forms a substantial fishery in the Brahmaputra in Assam. The proposed Farrakka Barrage across the Ganga unless provided with a suitable fish pass, is likely to affect the rich Hilsa fishery over hundreds of miles of the Ganga.

ESTUARINE FISHERIES

All the major rivers of India have extensive estuarine areas and besides these there are a number of brackishwater lakes in various parts of the country. The estuaries of the rivers, Ganga, Mahanadi, Godavari, Krishna and Cauvery and the brackishwater lakes of Chilka and Pulicat on the east coast and the estuaries of the Narmada and Tapti and the backwaters of Travancore-Cochin in Kerala are important fishery resources. The total extent of the estuarine areas is estimated to be about 3000 sq. miles. One main feature of the estuarine fisheries of India is that their exploitation is rather unbalanced. In the Sundarbans area of the Gangetic delta, about 400 sq. miles of which is in West Bengal, there are areas which are rather intensively exploited, but the major part of the resources are not fully utilized on account of the fact that these areas are surrounded by thick jungles and the available means of transportation are far from satisfactory. It is estimated that on an average about 95,000 mds. of fish are caught from the estuarine areas of West Bengal. It has to be realised that large-scale fishing is carried out in the area only for a period of about 3 months during the winter season in the highly productive areas of the lower estuaries in the Sundarbans. From about the month of March the weather conditions become too unfavourable for the operation of small sailing boats and the fishermen who camp in the area for the duration of the season return to their homes in the inland areas. The major fisheries of the Sundarbans bear on the Hilsa and other clupeids, the Bhekti (*Lates calcarifer*) the Mullets (different species of *Mugil*), Catfishes like *Tachysurus jella, Osteogeneosus militaris, Plotosus canius* and *Pangasius pangasius*, Threadfins: *Eleutheronema tetradactylum, Polydactylus indicus* and *Polynemus paradiseus,* the Bombay-duck, *Harpodon nehereus,* Jew fishes: *Pama pama, Sciaenoides biauritus* and *Johnius soldado* and various species of prawns, the more important of them being, species of *Penaeus* and *Metapenaeus.* In the upper stretches of the estuary considerable quantities of Palaemonid prawns are also landed. The resources of the Mahanadi estuary are very much under-exploited, largely on account of lack of transport facilities. The attempts of the Orissa Fisheries Department have resulted in the organisation of a small-scale fresh fish trade in the region, but there is considerable scope for the expansion and intensification of fishing in the area. The Bhekti, Hilsa, Threadfins, Mullets (*Mugil cephalus* and *Chelon macrolepis*), Jew fishes and Penaeid prawns constitute the major portion of the catches from the Mahanadi estuary. The Chilka lake is the largest brackishwater lake in India and is about 400 sq. miles in extent producing on an average about 88,000 mds. of fish per year. On account of the shallow nature of the lake, fishing operations are comparatively easy here and during recent years there has been fairly intensive exploitation of the fisheries. It is suspected that the stocks of fish in the lake are being overfished. Prawns constitute an appreciable proportion of the catches from the lake, the annual production being around 18,000 mds. Other major fisheries are of the Clupeids, the Hilsa and the Mud Shad, *Nematolosa nasus* being very important among them, the Mullets which constitute 10 to 16% of the total catches, the Catfishes, and the Threadfins. The Pulicat lake and the backwaters of Travancore-Cochin also afford very lucrative fisheries. The potentialities of the resources of these areas require further investigation. Though considerable quantities of fish are landed from the estuarine areas of many of the rivers on the West Coast, detailed information is not yet available of their magnitude. The backwater Oyster, *Ostrea madrasensis* abounds in all the estuaries and backwaters of the east and west coasts. The clams, *Meretrix* spp. form extensive beds in many estuarine areas and are of great food value.

Management of estuarine fisheries

The problems of the capture fisheries of the estuaries relate to the exploration of unexploited or under-exploited resources and the proper management of the existing fisheries. By the introduction of suitable types of fishing gear which can be operated from small power boats it may be possible to conduct fishing in the large estuarine areas of the Gangetic delta and of the Mahanadi throughout the year. This will result in enhanced production of fish and a more continuous supply of quality fish in good condition. Exploratory fishing experiments with this view will soon be initiated in the Sundarbans by the Central Inland Fisheries Research Station. Many of the estuarine fisheries exhibit very marked fluctuations in production and this has led to a general belief that the fisheries are getting depleted. This is particularly so in the case of the Hilsa which shows periodic fluctuations in abundance. In such fisheries it is essential to determine the magnitude and dynamics of the populations and the factors that are responsible for the fluctuations in the abundance of the fish. This information is essential for predicting the magnitude of the catches that can be expected from year to year and the optimum catches that a fishery can yield. One main handicap for such studies is the lack of reliable statistics of fish catches which form essential information for any detailed examination of the fisheries. Even though the dispersed nature of the fisheries render the collection of catch statistics from estuarine areas extremely difficult it has been possible in recent years to organise collection of reliable statistics of fish landings from the estuaries of the Hooghly, Matlah and Mahanadi rivers and the Chilka lake. The estuaries form nursery grounds of several marine and freshwater species and so large number of young and immature fish are caught in small-meshed nets from these areas. Ways and means of preventing this without causing hardship to commercial fishermen have to be devised.

Many of the estuaries are getting silted up rapidly or getting cut off by the formation of sand bars and this is believed to be affecting the productivity of these areas. In areas like the Chilka lake where the adult fish have to migrate to the sea for spawning and the young ones have to enter the lake through a narrow channel, periodic dredging or other physical improvements may be required to maintain the productivity.

CULTURE FISHERIES

Culture fisheries resources in India may broadly be divided into those of freshwater and of brackishwater. They are more or less impounded waters. Fish culture, in its true sense, is practised mostly in North Eastern part of India in the States of Bihar, West Bengal and

Orissa. In the low-lying deltaic regions of the Ganga and the Mahanadi rivers where the drainage system is poor, large number of pits are dug to take out earth for raising embankments, construction of houses, brick making etc. and these abandoned pits in which water accumulates serve as fish ponds. There are very large numbers of such ponds of varied dimensions in these States. Larger accumulations of water in natural depressions of land and spill areas of different rivers are generally known as the *jheels* and *bheels*. On account of the richness of the soil in this part of India, these waters are highly productive. Fish culture in this area is an ancient industry. The main fishes cultivated in the area are the major carps—*Labeo rohita, Catla catla, Cirrhina mrigala* and *Labeo calbasu* which grow quickly to a large size. Since these fish do not breed in confined waters, their eggs and larvae along with those of other fishes are collected year after year from rivers and stocked in fish ponds. All the operational techniques from collection of fish seed from rivers to the pond management are so backward and wasteful that the annual yield from such waters rarely exceeds about 500 lbs. per acre. A few fishes—*Anabas testudineus, Clarias batrachus, Heteropneustes fossilis* and *Channa* spp. are also cultured to a small extent.

In the peninsular India, fish ponds of the type in West Bengal are rare except in Kerala but there are very vast number of tanks, mostly for irrigation purpose, constructed in various drainages which support fishery of some magnitude. Majority of them are only seasonal tanks which dry up during summer months. Fish harvested from them are mostly wild fish. In Madras State, however, an extensive stocking programme of the tanks has been undertaken for the past several years. Fish fry are collected from several river sources and stocked in the tanks. *Chanos chanos* fry collected from the sea near Pamban is extensively used in Madras State for stocking the tanks and reservoirs. With the increased appreciation of fish culture in India in recent years there is now a regular trade in quick transport of fish seed of major carps from West Bengal to several States in India.

There are very extensive saline swamps all along the coasts and particularly in the deltaic areas of the major river systems in the country. These swamps are ideally suited for conversion into fish ponds. Traditional practices of culturing fish in embanked brackishwaters exist in West Bengal. Strong embankments are constructed around low lying areas and converted into what are locally known as *Bheris* and these are stocked with the fry of Mullets, Bhekti, prawns etc. which are taken in with the tidal water. Though the fish cultural practices are far from intensive, a production of 150 to 500 lbs. per acre is obtained from these *bheris* and a considerable proportion of Bhekti, Mullets and Penaeid prawns that come into the markets of West Bengal are caught from these bheris. In Travancore-Cochin in Kerala, brackishwater fish culture is conducted in low-lying paddy fields. After the harvesting of the paddy the fields are stocked with young Penaeid prawns and fish fry that come in with tidal water. The production from these paddy fields is appreciable and consists mainly of prawns which form about 80% of the crop, the rest being mullets, pearl spot, etc. Experimental brakishwater farms have been constructed in recent years in a few States and experiments have shown that a much higher production of fish can be obtained from brackishwater ponds by following more intensive culture practices. Species like *Mugil cephalus, Mugil tade, Chelon macrolepis, Mugil parsia, Chanos chanos, Etroplus suratensis, Lates calcarifer, Penaeus carinatus, Metapenaeus* spp. etc. are well suited for culture in brackishwaters. These species when acclimatised thrive very well in freshwaters and are therefore suitable for stocking inland ponds also.

The methods of brackishwater fish culture practised now in India are far from intensive. The *bheris* are too large to effect proper control of conditions and it is essential to improve the layout of farms to obtain higher yields. Since no selective stocking is practised, many uneconomic species of fish etc. enter the ponds and compete for food with the cultivated fishes. Methods of selective stocking have to be evolved and possibilities of fertilizing brackishwater ponds with cheap and easily available fertilizers have to be explored. Brackishwater fish farming which is now restricted to only a couple of States in the country has to be introduced in other coastal and deltaic areas also to increase fish production.

Pond management

Although the resources for fish culture are very extensive, more than 50 per cent of water areas are at present not being utilized for fish culture on account of the administrative and technical problems confronting them. Even in waters where fish culture is being conducted the cultural practices are only empirical and the production rate is rather low. In recent years extensive researches have been carried out by Central and some State fishery organizations on fish culture practices directed towards optimum fish production. The Pond Culture Division of Central Inland Fisheries Research Station has evolved improved methods of nursery and pond management, determining optimum stocking rate, mixed farming, reducing mortality in ponds and during transport, increasing productivity of ponds, eradication of aquatic weeds, eradication of insect and fish predators and inducing breeding of carps by artificial flooding of ponds and by injection of pituitary hormones. Experiments have also been carried out on suitability or otherwise of certain exotic fishes for culture in different parts of India. Based on improved techniques it has now been possible to obtain maximum yield from nursery ponds and transport fish fry over long distances with negligible or no mortality. The Central Ministry of Food and Agriculture has also set up Fisheries Extension Units in a number of States for popularising improved methods of fish culture amongst fish farmers.

Problem of fish seed

On account of expanded fishery activity in various States in recent years there has been a great demand for quality fish seed for fish culture purposes. The fish which are best suited for growing in confined waters are the major carps, Rohu, Catla, Mrigal and Calbasu. It is well-known that these fish do not ordinarily breed in confined waters. Their young ones (fish seed) are collected year after year mainly from the Ganga river system in West Bengal and Bihar and partly from the Mahanadi river and distributed for growing them in impounded waters. The collection and distribution of fish seed is a well-organised industry in West Bengal.

An assured supply of pure quality fish seed is an essential pre-requisite for successful large-scale fish cultivation. The present system of collection and distribution of fish seed has several disadvantages. The resource is limited to certain localised areas and transportation of live fish seed is very expensive. Further, the spawn collected from the rivers will be of several species of fishes often belonging mostly to uneconomical fishes.

In order to obviate these difficulties experiments were conducted by the Pond Culture Division of the Central Inland Fisheries Research Station to induce the major carps to breed in confined water by injecting them with pituitary hormones. During the fish breeding season of 1957 the experiments were successful in respect of all the major carps. This programme was intensified during 1958 at a number of centres and it was possible to produce large quantities of fish seed of major carps on a commercial scale in Assam and Orissa. A brief training in the techniques relating to such experiments was given to State Fisheries Officers and the Fisheries Extension Officers. Reports have been received of the success in such experiments from Andhra Pradesh, Uttar Pradesh and Madhya Pradesh. If suitable arrangements are made to carry out this work at a number of places it is possible to produce large quantities of pure fish seed of any desired species on a commercial scale in various parts of the country.

Aquatic weed control

One of the main causes of non-utilization of a very large number of ponds and *bheels,* particularly in West Bengal, Assam, Orissa, Bihar, Uttar Pradesh and Madhya Pradesh, is the excessive growth of aquatic weeds in them. About 50—60 per cent of cultivable waters in these States are almost choked with weeds rendering them partially or completely unfit for fish culture. Several reservoirs and irrigation canals have also the problem of excessive weed growth. The floating, marginal and emergent weeds do not present such a difficult problem. It is the submerged vegetation like the *Hydrilla, Ottelia, Vallisnaria, Naias, Utricularia* and *Chara* which are most obnoxious and render the waters unfit for fish culture. These weeds interfere with the movement of the fish and also hinder fishing operations. The weeds also deplete the water of much of the nutrients, which would have been otherwise available in making the pond productive in respect of fish food. A thick bloom of undesirable algae is also harmful since they choke the gills of fish, cause oxygen depletion during their mass decay and sometimes produce toxic substances.

Experiments have been conducted both by the Central and State Departments of Fisheries to evolve suitable methods of eradication and control of aquatic weeds. Mechanical methods which involve the use of bottom rakes, weed cutters and other appliances have proved to be uneconomical especially in respect of submerged weeds as the weeds regrow very rapidly. Spraying of diesel oil and power kerosene has also been tried. The application of Chlorobenzene and coal tar napthas etc. and also hormone weedicides though effective, are very expensive. Copper sulphate and Sodium arsenite are effective against most submerged weeds but they should be used in low doses as otherwise they will be toxic to fish life. As most of the ponds in rural areas are used for drawing water for domestic use or for cattle, there is objection to the use of such chemicals for weed control. This work is still in the experimental stage. Since the weed choked condition of vast areas of fertile waters is one of the main causes of their dereliction it is very essential to find an early and economic solution to this problem.

Pond soils

The nutrients of the pond soil determine, to a large extent, the productivity of a pond. A survey of the chemistry of pond soils conducted recently by the Central Inland Fisheries Research Station from a large number of ponds in areas of different soil conditions has revealed that the variability in the productivity of ponds is largely due to differences in the chemical composition of pond soils. While considerable stress is laid by aquiculturists on dissolved nutrients in water, there is little attention paid to the study of nutrients of the soils. The study of only the water without reference to the soil has led to erroneous conclusions. Artificial fertilization of fish ponds is only a corrective treatment to the pond soil for nutrient deficiencies. The effect of fertilizers on water medium is only very temporary.

While the nutrients of the pond soil and the catchment area are largely responsible for the productivity of newly excavated ponds, the biological processes occurring in the older ponds and the decomposition and sedimentation of organic matter change the bottom conditions. The soil substratum in a pond can be divided into two biologically significant layers, the upper layer consisting of loose well-aerated colloidal organic matter and the lower layer of an anaerobic zone containing mineral matters of varying composition. The upper colloidal layer is highly absorptive and readily absorbs ions of phosphate, potassium and ammonium while nitrate and nitrite ions are poorly absorbed. Experiments with radioactive phosphorus have indicated an exchange process between mud and water which resulted in the major quantity of added phosphorus being adsorbed by the mud. The texture and composition of the bottom mud play an important role in determining the productivity of a pond. Similarly in brackishwater *bheris*, the extent of the growth of benthic algae, which is the main food of many fishes in such waters, depends on the available nutrients in the soil.

Reclamation of swamps for fish culture

There are vast swampy areas spread over different parts of India particularly in the deltaic regions. These are at present practically waste lands. A survey of such areas has been conducted in Orissa State and there are in this State more than a hundred thousand acres of such swampy areas. Such areas range from 5 to 200 acres in different parts of the State. Some enterprising fishermen's cooperatives have utilised such areas for construction of fish farms. The Orissa Government has undertaken an extensive programme of reclamation of swamps for construction of fish ponds. The Department of Fisheries in Orissa has established a number of fish farms by reclaiming swampy areas and the fish production in the State has thereby increased considerably. It is now clear that the money invested in reclaiming swampy areas is justified. It is hoped that other States where this problem occurs will follow the example of the Orissa State.

Utilization of sewage for fish culture

In several countries raw or treated sewage from towns and villages are used for manuring fish ponds. In India there are instances of high production of fish in sewage-fed ponds and tanks. The spill area of the defunct Bidyadhari river near Calcutta has been reclaimed and a large fish farm has been established by an enterprising Fishermen's Cooperative Society. Calcutta sewage is being taken to manure the fish ponds and their productivity is comparatively high. A number of problems relating to utilization of sewage for fish culture are being investigated by the West Bengal Fisheries Directorate in an experimental fish farm in the area.

High production of fish has been observed in the Belandur tank near Bangalore which receives part of the town sewage. Another instance of high production of fish in a sewage-fed water is in Webster Moat near Tanjore in Madras State where an annual yield of over 10,000 lbs. of fish per acre has been reported. There is good scope for stepping up fish production by undertaking fish farming in the sewage outfall areas nearabout towns and by using compost manure in rural areas for fertilizing the fish ponds. Sewage is beneficial in making a pond productive only if it is taken in certain dilution. Precaution should be taken to sediment the suspended matter and also maintain the requisite level of dissolved oxygen.

Fish mortality

Sudden and large-scale mortality of fishes in ponds is a common occurrence in India particularly during the summer months. Since the total quantity of fish destroyed due to such mortality is very high it is essential to take precautionery measures to check wastage of fish in this manner. The extent of mortality depends on the causative factors and their severity. A number of investigations carried out in this connection have revealed that the causative factors are of two kinds, biological and physico-chemical. The former includes mainly factors like lack of food, parasites like fungal and bacterial infection and also infection by Argulus, flat worms and Myxosporidia. The physico-chemical factors which are involved directly as the exclusive or contributory causes of fish mortality are water temperature, turbidity, pH, dissolved oxygen, obnoxious gases produced by organic debris at the bottom of the pond and caustic chemical pollutants.

The lack of food in a fish pond is generally due to deficiency in nutrient salts in water. Corrective measures have to be taken by fertilising the pond with required manures. Fish affected by external parasite is generally treated with external baths with common salt, copper sulphate, potassium permanganate and other chemicals. Sometimes the entire pond is treated with a small dose of gammaxene. There are other suitable remedial measures for internal parasites. The oxygen depletion which is a principal cause of fish mortality is prevented by removing excessive organic debris accumulated in the pond. The pond should be regularly netted so that the poisonous gases do not get accumulated and there is a thorough mixing up of all the layers of the water.

Jute production in India has almost doubled since last three years. This has posed a serious problem on fish culture in West Bengal, Bihar and Uttar Pradesh. The retting is done in ponds and also running waters. Large scale mortality of fishes in ponds in which jute retting is carried out have been reported from several areas. There is thus a clash between programmes of increased fish and jute production, both of which are equally important to our national economy. Investigations are now in progress to determine in what manner the deleterious effect of jute retting on fish culture can be minimised.

Introduction of exotic fishes

Although a number of attempts have been made in India to introduce exotic fishes, none of them have established themselves as a commercial fishery. The sport fishes like the Brown trout (*Salmo trutta fario*) and the Rainbow trout (*Salmo gairdnerii gairdnerii*) have, however, established themselves very well in Kashmir, Himachal Pradesh and Kumaon (Uttar Pradesh) where they offer good sport for the anglers. Even Gourami (*Osphronemus gorami*) which is considered an excellent food fish, though thrives and breeds well in Indian waters, has not been successfully cultured to form a commercial fishery.

In recent years great caution is being exercised in regard to the introduction of exotic species for cultural purposes since they are likely to upset the biological balance of the indigenous fisheries. The Fisheries Research Committee of the Government of India is periodically reviewing and making suitable recommendations in regard to introduction and extension of area of culture of exotic fishes in India.

The mirror carp *Cyprinus carpio specularis* introduced into Madras in 1939 has proved to be a very useful fish for culture in India. This fish breeds in impounded waters generally over elevations of thousand feet above sea level. This fish is now being used extensively for culture in uplands all over India. The pure strain of Common Carp *Cyprinus carpio*, however, breeds in low elevations. A consignment of this carp was recently obtained from Bangkok and experiments are being conducted to find out its suitability for its introduction into low lying areas in India.

Tilapia mossambica was introduced into Madras in the year 1952. It is a very prolific and hardy fish. Since it is feared that the introduction of this fish into carp culture areas in India might affect the carp fisheries, great caution is exercised in its extension into carp culture areas. At present its culture has been confined to the narrow strip of West Coast, west of Western Ghats and the Southern portion of peninsular India. Investigatoins are, however, being carried out on this fish to find out how far and in what manner this fish affects carps at different phases of cultural operations.

Fishery statistics

Fishery statistics is an essential pre-requisite for formulating plans for fishery research and development. It may be broadly divided into economic aspects such as resources, production and utilisation and the biological aspects which deal with the accurate assessment of fish populations and other biological studies connected with it. In recent years considerable importance has been given in India to collect fishery statistics. The Fishery Survey Division of the Central Marine Fisheries Research Station has made substantial progress in regard to collection of catch statistics from the marine fisheries all over the country. The biological statistics on fish populations and allied subjects are being collected by both the Fisheries Research. Institutions.

On account of highly dispersed nature of inland fisheries it has still not been possible to get accurate statistics on their resources, production and utilisation. It is very essential that detailed surveys should be undertaken to clearly assess the water areas available under capture and culture fisheries, the extent of present exploitation, and area now being used for fish culture, the fishermen population, fishing craft and gear etc. The Central Inland Fisheries Research Station has recently carried out an inventory of the fishermen and fishing craft and geer along the Hooghly, Matlah and Mahanadi estuaries, the Ganga river and organised a sampling survey to estimate the total catch and catch-per-unit-of-effort data. Attempts are also being made to evolve a suitable sampling technique for collection of statistics on culture fisheries.

CONCLUSION

I have attempted to describe here, in outline, inland fishery resources of India and some basic problems peculiar to them. Organisation of minimum facilities for the proper utilisation of resources in the production and distribution phases of the industry are equally important in the development of inland fisheries, as in marine fisheries. The Central and the State Governments are taking active interest in the development of fisheries in the country, but so far only a beginning has been made in this direction. We owe it to some of our pioneer fishery experts to have made our Governments recognise the importance of stepping up fish production ; but still the potentialities of fishery development have not been fully realised. There is a deplorable lack of public interest in regard to fisheries development and an important step necessary to improve the tempo of fishery development in this country is, in my opinion, development of enthusiasm among our people. Intensive investigations on various aspects of fisheries are pre-requisites for scientific fishery development. Detailed fisheries research requires the help and cooperation of specialists in various branches of biology and other sciences. Besides the Biologists ; Statisticians, Chemists, Physicists, Engineers, Naval Architects, Technologists, Economists and specialists in other fields can make notable contributions to the advancement of this science and consequently the fisheries development. I take this opportunity to appeal to my fellow scientists to bestow their earnest attention to solve the intricate fishery problems, to the administrators and planners to give fisheries the high place that it deserves in the national development programmes and to the general public to evince greater interest in the development of this vitally important national resource.

SECTION OF ANTHROPOLOGY AND ARCHAEOLOGY

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PRESIDENTIAL ADDRESS

THE NEOLITHIC PATTERN OF INDIA

I. INTRODUCTION

The first find of a neolith in India was made in 1860 by H. P. Le Mesurier who drew attention to his discovery of ground and polished stone implements in the valley of East Tons River, in the then United Provinces. For 80 years since then, neolithic artefacts of various types have been collected in all parts of India from the surface. The collection, however, proceeded on unscientific lines based on haphazard selection and such material has found its way into museums in India and abroad without any value for cultural or chronological classification. Even with a vast lithic collection, all that could be said of them, even as late as 1944, was that "the Neolithians of India were principally toolmakers and hence culturally inferior to the Neolithic Egyptians who knew, in addition to tool-making, agriculture, domestication of animals, manufacture of pottery and textile industry". Later still, in 1949, Worman stated that there was no Indian site or implement yet known to him that could surely be called "neolithic". He would not have made this statement, had he known Wheeler's excavation, in 1947, of the Brahmagiri site in Northern Mysore confirming the (chalcolithic) neolithic culture identified as early as 1942 by Krishna.

By definition, Neolithic Culture is a Stone Age Culture, and the primary trait that sets the neolithic culture apart from other Stone Age Cultures is that of intentional food-production as opposed to mere food-gathering as a means of subsistence. This trait is found in the occupations of agriculture and animal husbandry. The secondary traits often found associated with neolithic culture are disclosed by pottery and smoothed stone tools. A full neolithic archaeological site may therefore be characterised by the presence of domesticated animals or plants, pottery and smoothed stone tools. The absence of metal in an archaeological complex containing these triple traits or stratigraphic evidence proving that the complex existed prior to the introduction of metal into the area, is also a prerequisite to the identification of a neolithic site or culture.

On the basis of this definition, Worman plotted the sites at which Indian smoothed stone celts have been found. They occur almost exclusively in Assam and Bengal, Central India and Southern India, south of the Gangetic plain, north of Pudukkottai and east of a line drawn in a south-south-westerly direction from Lucknow in the Uttar Pradesh to Goa on the west coast. The fact that the distribution of these celts is confined to the eastern half of India, has led him to an interesting speculation as to the place of origin of most Indian neolithic celts and their technique of manufacture. As a result of their typology and distribution, he has drawn tentative conclusions (which as he himself admits) are based on incomplete information and should be checked primarily, more with the archaeology of the future than with that of the past. They are briefly: (i) in India itself there is no positive archaeological proof in regard to the existence of neolithic people at any time before or after the use of metal came into being ; (ii) Indian smoothed stone celts of neolithic type, regardless of their cultural affiliation, appear to have mainly been derived from South East Asia at different dates ; and (iii) a typological comparison of Indian and Far Eastern celt types corroborates the above postulate and supports the theory that certain Indian types are earlier in date than others, and that the eastern half of India belonged to a fairly large South and S. E. Asiatic culture, throughout which the evolution of post-pleistocene prehistoric cultures were apparently similar.

Central and Western India, as depicted by Worman were "terra incognita" because there were no neolithic finds beyond what Foote had collected round about Maski and Raichur. With the discovery of an indigenous polished Pointed Butt Axe Culture at Brahmagiri by Wheeler, Worman's postulates No. (i) and (ii) are untenable and the rest have all to be revised in the light of recent discoveries in India and the Far East by Sankalia, Subbarao, Dani, Sen, Ray, Tweedie and Colani.

A brilliant decade followed the Brahmagiri excavation by the location of many centres of a new (chalcolithic) Neolithic culture in Central and Western India as revealed by the excavators at Nasik on the Godavari, Jorwe and Nevasa on the Pravara, a tributary of the former river, Maheshwar and Navdatoli on the Narmada, by Sankalia ; at Tripuri in the upper reaches of the Narmada Valley by Dikshit ; at Bahal on the Girna (a feeder of the Tapti) by Deshpande ; at Maski in Krishna basin and at Prakash on the Tapti both by Thapar ; and at Nagda on the Chambal by Banerjee. Recent surface explorations also have brought to light many other similar sites in Bijapur, Belgaum and other places, all situated in the stretch of land between Nagda on the north and Brahmagiri in the south roughly extending from the Tropic of Cancer to 15° N-Lat.—a distance of about 600 miles. The fact that this culture transcended the respective limits of the latter-day Aryan and Dravidian language zones may not, as Ghosh points out, be without import. There is a broad similarity in the equipment of this culture, namely the use of painted pottery, and to a restricted degree of copper, the typological similarity of polished stone axes of Brahmagiri and Nevasa and the existence of ribbon flake microliths.

Dani made a special study of the Neolithic culture of Eastern India and South-East Asia and succinctly made out that the neolithic elements have come in different waves at different times from South-East Asia into Eastern India through Burma and that a definite chronology can be ascribed on the basis of a black polished ware associated with the specialised tools of the Later Complex in Malaya.

Similarly, the isolated loessic neolithic culture of Kashmir can be accounted for by the impact of a neolithic culture of the pre-Harappan period, located at Baluchistan.

We have, therefore, four neolithic provinces in India, viz. A, B, C and D.

I propose to describe these four provinces in detail in this address and deal with the origin of the neolithic traits in these provinces.

2. THE PROTO-NEOLITHIC PHASE IN INDIA AND PAKISTAN

Before dealing with the quadruple division of the Indian neolithic complex, it is necessary to review briefly certain lithic industries brought to light in the Narmada basin at Hoshangabad in Madhya Pradesh by De Terra and in the Sabarmati basin in Gujarat by Sankalia and Subbarao, and in Mirzapur (U.P.) by Cockburn, besides those of Sukkur, Rohri, Karachi and other places in Pakistan. All these have to be considered as proto-neolithic in character, forming the basis of the Indian Neolithic Complex.

Narmada Valley.—The new alluvium of the third aggradational phase in the Narmada is equated to the cotton soil, corresponding to terrace V of the Sohan in the Panjab. In its basal gravel and sands and in the lower few feet of 'regur', De Terra and Teilhard found a flake industry in jasper and flint dominated by microlithic blades and scrapers homologous with the mesolithic culture, akin to the Capsian of Syria and Africa. They call this industry proto-neolithic or even a late industry that may have flourished in recent times in the rock shelters near Hoshangabad and elsewhere. Since occasionally it contained fluted cores, which are characteristic of the succeeding proto-historic cultural phase, as seen at Maheshwar lower down the river, typologically and technologically this industry leads to the advanced microlithic industry of the succeeding chalcolithic phase spread all over Central and Western India. Since stone mace-heads with typical hour glass section are found stratigraphically over this industry at Maheshwar, De Terra's description of it as proto-neolithic is confirmed by Sankalia.

Sabarmati Valley.—Further north, in the Sabarmati valley, there is a marked concentration of microlithic sites at Langhnaj near Mehsana in North Gujarat. Even in Central Gujarat, the same culture predominates. In the Langhnaj industry three zones of microliths were found without any variation in types. The commonest type of implements is a lunate or crescent. There are doubtful remains of dog and bovine fauna ; but the food remains of Langhnaj indicate game animals. In the first zone, extending from the surface to a depth of 3 feet, the microliths are associated with modern-looking potsherds along with a long tanged iron dagger. In the second zone at a depth of 3 to 4 feet where an ancient land surface is met with, a different type of pottery is found with incised lattice decoration. The pottery is thin, red-slipped over a pale brown surface with a cow-dung-like greenish-yellow core. Besides microliths, a large quartzite mace-head with hour glass-like section and two neolithic celt pieces of chlorite schist belong to this zone. The third zone from 4 to 8 feet is the pure microlithic zone. The sandstone quern fragments are generally found below 4 feet which is below that at which pottery has been found and therefore some primitive form of agriculture was practised before pottery came into use. Thus in Gujarat we have evidence of a microlithic folk being introduced to agriculture and pottery and the original mesolithic food gatherers becoming neolithic food producers, albeit, on a very restricted scale.

Kon Ravines.—A flint industry was reported at Mirzapur in the Kon ravines by Cockburn in 1894. He found neolithic polished celts of basalt and flakes and blades of chert derived from the Lower Vindhyan Lime-stone and pointed out that the only other locality in India where such flakes and blades have been found was Rohri in Sind.

Sukkur and Rohri.—A stone industry that might be looked upon as preparatory to the chalcolithic cultures of Indus valley and Baluchistan is probably that found at Sukkur and Rohri. The Sukkur and Rohri sites, though connected geologically and typologically, present distinct variations.

In the Sukkur industry, with no apparent stratigraphic sequence, the heavier tools, such as handaxes and big cores, are found concentrated near the base and large scrapers are on the top interspersed with blades. On grounds of patination, in the absence of pottery, the implements can be placed into three groups—A, B, and C—which merge into each other. Group A shows dark-brown desert patination with lustre, blades being in the majority over flakes. Cores are very few. Group B shows desert patination with no lustre ; artefacts similar to those of Group A, the chief difference being the presence in this group of concavo-convex flakes. They show levallois technique with flake-scars. Blades thinner. Flakes more than in A, cores common as in Group C. Group C is fresh and unpatinated ; flakes greatly outnumber blades. Concavo-convex flakes as in Group B. Cores small, conical and fluted ; flake-scars covering at the apex. These are similar to those in the earliest levels at Mohenjodaro.

The Rohri industry with large quantities of flint cores and flakes falls in Group C of Sukkur. There is also pick-like tool trimmed out of a thick blade which has been described by Subbarao as a crested- guiding-ridge-flake. Similar flakes have been found in the Sturge collection of the British Museum from Sukkur and Rohri, varying in length from 10 to 12 inches.

The combination of so many different techniques in these industries suggests that these were very late and is indicative of an age approaching the earliest chalcolithic civilization of the Indus valley. From the geological angle, however, De Terra ascribes to these Stone Age sites, a somewhat greater age than what their typological evidence would admit. This accords with the evidence from further West, in Palestine and Iraq. In the Fertile Crescent, such an industry appears in purely Neolithic levels, as at Jericho, where this new technique of crested-guiding-ridge-flake for the mass production of blades started among the earliest agricultural communities.

Karachi.—Another lithic industry that deserves consideration in this context relates to a golf-course at Karachi, wherefrom Todd collected lithic tools and deposited them in the British Museum. Lal, who studied them, points out that the artefacts include long blades, points, scrapers, trapezes and crescents, besides fluted cores. Subbarao, who also saw the same collection, points to the existence of a crested flake.

Kashmir.—Pottery and flakes found at Sombur in Kashmir and in the alluvial deposits on the Jhelum and also at Burzahom and Pampur, led De Terra to state: "In all these places it was certain that the flakes are associated with pottery-bearing layers of either neolithic or historic date. Notwithstanding these observations, it is still possible that the flakes found in the lowest Jhelum terrace V, represent a late palaeolithic or proto-neolithic culture". The evidence of Uchali, west of Naushera in the Salt Range, West Pakistan, seems to bear this out, as stray finds of microliths of jasper or flint from the Potwar loess surface may have been derived from a fossil soil of sub-recent origin. Besides, there was the association of a burial in the implementiferous layer, which yielded hand-made pottery presumably of neolithic type.

Zhob Valley.—In the Zhob valley, Ross demonstrated five occupational deposits at Ranagundai. The earliest level is characterised by plain hand-made pottery and flint blades. Domesticated animals are represented by sheep (*avis Vignei*), horse (*Equus Cabalus*) and cattle (*Bos Indicus*). The second phase is distinguished by wheel-made painted red pottery, bearing designs of stylized bull and black-buck. There is a striking similarity between this pottery and that of Hissar I and it is not unlikely that it represents an infiltration from the Iranian uplands in the second half of the 4th millennium B.C.

The existence of a pre-pottery microlithic culture has been reported by Fairservis at Kile Gul Mohamad in Baluchistan. Here, below the pre-Harappan Kichibeg culture, he found two phases: first, a pre-pottery microlithic culture, Kile I, characterised by flint flakes and fine polyhedral cores ; it was followed by Kile II, marked by the presence of wheel-made and hand-made pottery, some crudely painted in black, red and brown with geometric and mat-marked designs. Stone axes, flake scrapers (flake-blades) and knives (blades) also occur here. Broadly, the Kile Gul Mohamad Culture may be placed early in the 4th millennium B.C.

The components of the proto-neolithic phases in India and Pakistan would show that if there were to be a real neolithic phase in the same region, it should exhibit a microlithic industry as a hold over into the neolithic, along with the ribbon blade industry of Sukkur and Rohri. This is exactly what has happened in the newly discovered (chalcolithic) Neolithic sites of Central and Western India, as far south as Brahmagiri. Polished stone axes have not been reported either in Central India or Western India in the proto-neolithic phase, and its evidence in Kashmir can be attributed to a western influence from the Zhob valley in Baluchistan and the Iranian Uplands, where a pre-Harappan neolithic culture is found.

3. PROVINCE A—CENTRAL AND WESTERN INDIA

Most of the (chalcolithic) Neolithic sites in Central and Western India are concentrated in the Deccan trap area, and located in the river valleys of Chambal, Narmada, Tapti, Godavari, Krishna and Tungabhadra. I, therefore, propose to make a rapid survey of the results of the excavations done in these river valleys and then finally discuss the significance of these discoveries from the point of view of their origin and diffusion.

CHAMBAL VALLEY

Nagda.—In Madhya Pradesh, more than 30 (chalcolithic) Neolithic sites were discovered in the Chambal valley. Banerjee undertook the excavation of two of the most tyical of these sites, Nagda and Ujjain, with a view to obtaining a cultural sequence for this region with particular reference to the (chalcolithic) Neolithic culture of this region.

The occupational deposits at Nagda, 32 feet in depth, show three cultural periods, resting on the natural black cotton soil. Periods I and II are (chalcolithic) Neolithic in character. The earliest, Period I, was represented by a 22-ft. thick deposit. The lithic component of this culture included microlithic tools, mostly parallel-sided blades and fluted cores of chalcedony, quartz and carnelian showing crested ridge. A few blades were retouched and the working side often serrated.

Ceramics consisted of a dominant red or cream coloured ware painted in black in various designs—horizontal bands, concentric semi-circles, connected loops, wavy lines, vertical radiating lines filled with hatched triangles along with Sun symbol and figures of antlers. There also existed a black-and-cream ware with oblique or vertical strokes and a crude grey ware with blackish core. Plain pottery was limited in quantity. The use of copper was restricted.

Period II was continuation of period I with microliths persisting but otherwise marked by the disappearance of the black-and-cream ware and the emergence of the wheel-made black-and-red ware with iron.

Ahar.—In the village of Ahar at Udaipur in Rajasthan situated in the catchment area of Berach, there is a cultural mound known as Dhulkot. The occupational deposit of 30 feet is represented by two main cultures, separated by a break. The first culture over the natural sandy soil could be divided into three phases with the characteristic black-and-red ware associated with a plain red ware, with incised designs on the shoulders. Ghosh has pointed out that this region is not far removed from the fringes of the horizon of the painted grey ware of North India. The microliths were also found in the middle and upper phases consisting of parallel sided blades and fluted cores with copper objects along with the black-and-red ware. The upper culture over the break is probably contemporaneous with the Kushan times.

NARMADA VALLEY

Maheshwar.—A small town in the Nimad District, is situated on the north bank of the Narmada, opposite which lies the tiny village of Navdatoli. While a few traces of proto-historic cultural phases of painted pottery and microliths were discovered at both the sites, the occupational mounds here introduced a hitherto unknown (chalcolithic)-Neoloithic phase in Central India styled Proto-historic by Sankalia. In the earliest phase I, over the black cotton soil, there is a crude microlithic industry characterised by irregular and fluted cores and discoids of jasper and chert. The succeeding phase II, 5 to 8 feet thick, is characterised by an advanced microlithic industry with painted and unpainted pottery. Besides lunates and trapezes the microliths are characterised by long parallel-sided flakes, serrated and blunted blades and cores of milky chalcedony, agate, jasper and chert. The most distinctive feature of this advanced microlithic industry is the deliberate use of the original fluted cores for making parallel-sided blades, pointed borers, etc., by alternate step-flaking. Other lithic characteristics are the flattish oval mace-heads, with an hour glass section, small stone-balls, battered at double ends, primitive querns and plano-convex pestles. The pottery from mounds I and II at Navdatoli shows a predominantly red ware. The red persists to the last, whereas the black gradually dies out. Among the painted sherds, the black-on-red forms about 89 per cent. The designs on the painted pottery include a variety of geometric and naturalistic designs and stylized human and animal motifs. Though no complete vessels were found, bowls and dishes with stands and wares having channels or cut spouts may be seen. Besides, there is also incised pottery. There is a very small amount of copper in the shape of hooks, pins and chisels.

The next period, III, is defined by the presence of the N. B. P. Ware, black-and-red ware and punch marked coins, with iron tools.

The (chalcolithic)-Neolithic culture is dated roughly before 500 to 1500 B.C. or earlier, since period III shows definite association of N. B. P. Ware and punch marked coins going to 400 B.C.

Tripuri.—In the upper Narmada valley, near Jabbalpur, Dikshit brought to light at Tripuri the existence of a puzzling microlithic industry in the lowermost brownish silty clay (black cotton soil).

Associated with the microlithic industry was a wheel-made, red, painted pottery with horizontal bands in black. The microliths consist of long blades (up to one and a half inches in length) retouched, with battered back and even occasionally serrated, along with a large number of lunates and triangles. But the association of the painted pottery with the blade industry in the black cotton soil at Tripuri would, however, bring it within the ambit of the proto-historic (chalcolithic) Neolithic culture of Central and Western India. Thapar points out, that if it is to be regarded as another facet of the post-Harappan (chalcolithic)-Neolithic culture, it is very difficult, at present, to get the extension as far as Tripuri, unless more sites between Maheshwar and Tripuri are discovered. The animal remains in this layer were those of the wild boar (*sus*) and ox or cow (*Bos Taurus*).

TAPTI VALLEY

Bahal.—Situated on the Girna river, a tributary of the Tapti, in East Khandesh District, Deshpande brought to light five periods in the occupational mound with breaks between Periods I and II, and again between Periods III and IV and established the (chalcolithic) Neolithic nature of Period I, having the same sequence as at Nasik.

Period I has two Sub-periods, A and B, both Neolithic. Sub-period IA, was distinguished by a thick grey ware of globular jar with a flared rim, reminiscent of the Brahmagiri burial urn, bowl with a flat base, incurved rim and had made jars with incised oblique and criss-cross lines, or dot-and-chain patterns and applique finger-tip designs. A few sherds of thin grey ware, with painting in red-ochre are also present. The tip of the knobs are also painted in red ochre.

The succeeding Sub-period, IB shows wheel-made pottery, painted in black on red ware with a variety of designs. A few sherds of a lustrous red slipped ware recalled the post-Harappan lustrous red ware of Rangpur as pointed out by Srivastava the carinated bowl and spouted vessel of the Nasik and Jorwe type occur along with a terracotta lamp with a stand in the upper levels of the Sub-period. Side by side, there appear for the first time a few sherds of burnished grey and black ware with oblique lines painted in white, as at Sanganakallu Phase II.

The lithic industry is essentially an urban industry of chalcedony, agate and jasper, mostly of parallel blades, sometimes serrated, and less frequently lunates and trapezes.

A limited use of copper is indicated by a shapeless lump of the metal.

Period II (*circa* 600-200 B.C.) marks a complete change with the emergence of iron and black and black-and-red wares, the latter being produced by inverted firing.

Prakash.—About 100 miles lower down in the Tapti basin from Bahal, Thapar excavated the chalcolithic mound, 75 feet high, at Prakash at the confluence of the Tapti and Gomai, exposing four cultural periods. The earliest, datable to first millennium B.C., used microliths. Copper, though known, was extremely scarce. The ceramic industry comprised a black-on-red painted pottery with designs consisting of diamonds, horizontal or oblique bands, crise-cross or wavy lines, ladder patterns along with animal motifs. In association with this ware, was found a thin burnished grey ware, as at Bahal, occasionally having linear designs in white. There were also thicker sherds of a coarser fabric in dull grey ware painted with ochre on the rim. The microlithic industry, in this period, consists mostly of parallel-sided blades, a few of them serrated, some backed and a few converted into points, along with crescents and trapezes. From the rarity of the polished axes, the (chalcolithic) Neolithic sites, located in the Tapti and the Narmada basins, are seen to be different from those of the Godavari, Krishna and Tungabhadra river basins.

Period II (*circa* 500 to 100 B.C.), separated by a sterile layer from Period I, representing a full-fledged iron-using culture, characterised by black-and-red ware along with sherds of the N. B. P. Ware, as at Bahal and Maheshwar, provides a datum for relative chronology.

GODAVARI VALLEY

Nasik.—At Nasik and Jorwe, Sankalia brought to light five main cultural Periods. The earliest occupational layer of black clay at Mathi-chi-Gadi (Nasik) is characterised by advanced microliths, in association with painted pottery and a large amount of ochre-washed ware. This phase was styled proto-historic by Sankalia and assigned approximately to *circa* 500-1500 B.C., or even earlier. Subsequent explorations in this region and in Ahmed Nagar have revealed a few identical elements of (chalcolithic) Neolithic culture at a number of places. About sixty per cent of the microliths were artefacts, such as cores mostly fluted, blades with mid-ridge, blades backed with steep retouch, lunates and a few obliquely blunted points. The distinctive light orange (ochre) coloured ware (O.C.P.) of this period is characterised by a powdery surface along with a few sherds painted in black over a reddish surface. Both these wares are wheel-made. Besides, a few vessels show spouts and carination, which do not recur in the historic period.

Other wares of Period I included a pale whitish red ware, in association with a grey ware, and a coarse black ware. The grey ware, being similar to the burial-urn at Jorwe and at Brahmagiri in Period IB, provides a link with the (chalcolithic) Neolithic cultures of these two regions.

Bowls and dishes, as well as globular vessels, are the distinctive types of Period I. Besides, the sherds indicate spouted vessels and bowls with carination, which do not recur later at Nasik, but were found in abundance, however, at Jorwe.

The bones found in this period are those of the domesticated buffalo (*Bos Bubalus*), ox (*Bos Indicus*), pig (*sus species*), sheep, goat and dog.

Jorwe.—It is a single-period site, on the left bank of the Pravara river, five miles east of Sangamner. The majority of the microliths are flakes and cores. They exhibit a special "crested guiding flake and keeled core technique" characteristic of the neolithic in Western Asia and the Aegean. There are parallel-sided blades with crested ridge, parallel-sided double-edged blades, saw-like blades, backed blades and a few crescents. There is a variety of fine fluted cores, fluted on one surface, flattened on the reverse, reminiscent of the "ripple flaking on Egyptian Neolithic tools from the Fayyum Desert".

The bulk of the pottery is wheel-made, showing spouted ware and a few hand-made large storage jars and dishes. The affinity of the painted pottery, particularly the spouts, painted along their lengths, with a single but identical spout in period I of Nasik, suggests that the Jorwe culture may be contemporary, at least in part, with the Nasik culture, found in the lowest black soil layer.

Nevasa.—The Ladmod occupational mound at Nevasa on the south bank of the Pravara in Godavari basin rests on black soil, as elsewhere. Five distinct cultural phases have been recognised by Sankalia.

The first phase is characterised by the presence of Brahmagiri type of polished pointed butt axes, a chisel and an adze, in trap, along with hammer stones, round sling stones of trap and quartz and microliths of chalcedony. The microliths are very similar to the blade industry of Maheshwar and showing the special technique observed at Jorwe. The use of metal in phase I is evidenced by the discovery of a copper or bronze bead, hook and a chisel indicating (chalcolithic) Neolithic age.

Except for large storage jars and burial urns, the pottery is wheel-made and painted in black on a fine red or chocolate surface. The commonest vessel is the bowl with a flaring rim and rounded base with long side spouts, painted along its length or at its edge. The painted designs are essentially geometric, besides a few animal motifs representing deer, graffiti figures of men, peepal leaves and basket patterns.

After the (chalcolithic) Neolithic occupation, the site remained unoccupied. The succeeding phase, II, separated by a sterile layer from the earlier phase, is characterised by sherds of a red and the N. B. P. wares and iron implements like sickles, daggers and plough-shares.

KRISHNA BASIN

Maski.—Thapar exposed at Maski in the Krishna basin, three occupational phases with a break between the (chalcolithic) Neolithic culture (period I) and the Megalithic culture (Period II). The cultural equipment of Period I is neolithic in character as evidenced by the most distinguishable microlithic industry of chert, agate, opal and carnelian, along with a meagre supply of copper, showing the essential neolithic economy of the culture. About 80 per cent of the microlithic industry includes parallel-sided "ribbon" blades and asymmetrical flakes, associated with parallel fluted cores. The blades range from 1½ to 5 inches in length and are reminiscent of the ribbon flakes of the Harappan civilization in West Pakistan. There are also examples of flakes with crested ridge. The whole complex is evidently dominated by an essentially urban blade industry, without any retouch, secondary work being always of a steep blunting nature. No polished stone axe has been recovered from the deposit of this period. However, the four surface specimens, in trap, of the pointed butt axe type of Brahmagiri, with lenticular section, can be assigned to this period, because of the undoubted association of the Polished Stone Axe industry with microliths both at Brahmagiri and Sanganakallu. The other specialised stone objects comprised spheroid balls of granite, showing flattened battered sides, indicative of their use as hammer stones. They are similar to those found at Navdatoli and at Brahmagiri in association with painted pottery and microliths.

The pottery at Maski is mainly wheel-made, though hand-made specimens are also present. There are two ceramic phases. The earliest phase is characterised by (a) dull grey ware, as at Bahal, sometimes mottled and (b) pinkish buff ware showing a greater frequency at the lower levels. Noteworthy of this phase, however, is the painted pottery with linear designs on red slip.

The animal remains in Period I reveal short-horned humpless cattle and also humped varieties (*Bos Indicus*) as at Harappa and Mohenjodaro, buffalo (*Bos Bubalus*), sheep (*Ovis Vignei*) and goat (*Capra hircus aegagrus*) resembling those of Harappa. This is contrary to the assertion of Haimendorf that the neolithic settlers in India kept pigs and fowls but lacked domesticated cattle. Allchin, in his excavation at Piklihal in Raichur District found a terracotta figurine representing a long-horned variety of cattle. This is also confirmed by Zeuner's identification of the cinder as accumulated heaps of cowdung from the ash mounds at Kupgal and Kudatini in Bellary District which is further supported by the identification of big bones of cattle in the ash mounds between Gaudur and Machnur near Lingsugur in Raichur District. The domestication of these animals demonstrates a pastoral economy of the settlers, tending towards food-growing. Deshpande reports about 15 chalcolithic sites in Bijapur District, in a very small area, in the Bhima basin which yielded black-on-red painted pottery and a thick grey ware associated with a specialised blade industry and fluted cores. In a few of the sites, neolithic polished axes in trap were also found.

Saletore found a neolithic polished axe in trap at Saptasagar in Belgaum District in the Krishna basin, south-west of Bijapur along with microliths and chalcolithic pottery. With the discovery by Lal and Deshpande of another chalcolithic site with painted pottery and microliths at Karhad in Satara District, the Krishna basin is linked closely with the Godavari (chalcolithic) Neolithic sequence obtained at Nasik, Jorwe and Nevasa, further north.

Nagarjunakonda.—About 250 miles east of Bellary, on the banks of the river Krishna, Soundara Rajan located a neolithic site at Nagarjunakonda.

His excavations have yielded polished axes in different stages of manufacture, in association with typical neolithic burnished grey (as at Maski) and reddish brown wares along with fragments of copper, besides animal bones. The animal bones belong to domesticated buffalo (*bos bubalus*) and spotted deer (*axis axis*). The culture seems to be analogous to the (chalcolithic) Neolithic culture of Brahmagiri, Sanganakallu and Maski.

TUNGABHADRA VALLEY

Brahmagiri.—At Brahmagiri, in northern Mysore, polished stone axes, microliths, painted pottery and megalithic tombs were found by Krishna in 1942, but no accurate information was available to determine their sequence. In 1947, Wheeler excavated the site at Brahmagiri and discovered a sequence, which has indeed become the yard-stick for understanding the existence of similar cultures in Western and Central India. The cultural sequence at Brahmagiri from bottom to top is: (1) A Stone Axe Culture 9 feet in depth, divisible into Sub-periods IA and IB, separated by a sterile weathered surface; (2) the Megalithic culture, 4 feet deep, followed by (3) the Andhra culture, extending to the surface for about 3 feet. The Brahmagiri Stone Axe Culture is characterized throughout by polished pointed butt axes of trap rock. The earlier examples show flattened section, but lenticular section is the normal. The axes are associated with microliths of jasper, flint, agate, opal and rock-crystal, amongst which the specialised geometric tools such as the trapezes, triangles and the crescents were very rare or entirely absent. A copper chisel found midway down the Sub-period IB and two small rods, one of copper from inside a burial urn and another of bronze from a middle stratum of Sub-period IB indicate both a knowledge and an extreme scarcity of the metal. A bronze finger ring was found from a late stratum of IB.

The pottery was hand-made, mostly of coarse grey in both the subphases in contra-distinction to wheel-made pottery of Period II and III. In the lowest black soil layer of Sub-period IA, occasional sherds of the painted and incised red or buff slipped ware are found, which, however, are absent from the upper layers of Sub-period IB over the sterile layer.

The range of patterns on the painted sherds show curvilinear lines representing a conventionalized plant pattern with no resemblance whatsoever technically or artistically to the Indus Valley ceramics. The incised sherds represent elementary herring or criss-cross lines. The majority of the sherds in Sub-period IB represent burial-urn pottery, mottled and of dull grey colour. The significance of the sterile layer is not yet known. Probably it represents a break in the occupation with temporary desertion of the site. This is certainly possible since the decorated and the incised wares stop at the sterile layer.

Lithic finds from Brahmagiri are mainly from Period I.

(a) The microlithic industry, an essential feature of the Stone Axe Culture, is crude in the extreme and rarely exhibits any attempt at retouching. Save for one crescent at Brahmagiri, there are no lunates, trapezes or scrapers in contrast to the earlier microlithic industries of the Mesolithic age. The following types of tools are known. The majority of them are double-edged blades in jasper without retouch a few of which exhibit serration on one edge. Ten per cent of the finished microliths were recovered from Sub-period IA while 90 per cent were recovered from IB. Some blades are of the battered back type. The technique of serration though known from the earliest level of the site was not widely applied. The serrated blades show no sign of gloss on the serrated or unserrated edges and are restricted to the low levels of Sub-period IB. There is also a crested ridge flake in this industry as pointed out by Subbarao.

The exact character of Brahmagiri microlithic industry is hard to be determined as fluted cores corresponding to the parallel sided blades are absent.

Of the stone axes of the pointed butt type, 15 complete and 29 broken specimens were found in Period I, in various stages of chipping, pecking, grinding and polishing, there being no proof for Haimendorf's typological evolutionary phases that chipped axes with only the cutting edge ground and polished preceded the axes ground and polished all over. Besides, the presence of cores and flakes of this material mostly in the strata of IA and in the low levels of IB indicates a local industry. Save for one small flat axe with roughly parallel sides converging abruptly to a pointed butt and 3 broken axes from IA, the majority of the axes were obtained from lower levels, with a unique stone adze from the higher levels of Sub-period IB. Again the axes fall into two groups, one with flattened lenticular section restricted to the lower levels and the other with ovoid section present throughout the Period. The other lithic antiquities in this Period, are saddle querns, rubbers and spheroid balls.

The pig or sheep seems to be the domesticated animal as indicated by a terracotta figurine found in the IB levels.

Sanganakallu.—Soon after the excavation at Brahmagiri, Subbarao explored the neolithic culture of the Bellary region, the pivot of the lower Deccan, and conducted an excavation near the rock shelter at Sanganakallu (Bellary). In the excavations he found a neolithic industry in Phase II associated with coarse brown-and-black and pale grey pottery along with a superior urban microlithic industry of chert, jasper and quartz. Below this and separated by a thin barren layer he discovered the earliest occupation of the site (phase I) characterised by heavily patinated flakes of trap and sandstone associated with a crude microlithic industry of quartz and chert without any evidence of pottery. The flakes are long and short exhibiting longitudinal and convergent flaking by levallois technique. The microliths are mostly of quartz, without any secondary retouch, fluted cores being very few, and on account of the bad material, no definite implement types could be made out.

The succeeding Phase II shows a continuous occupation by the highly developed Neolithic Culture in Bellary, divisible into two Sub-phases on the evidence of associated pottery. The lower Sub-phase has a pale-grey ware along with a few sherds of coarse brown-and-black hand-made pottery as at Bahal and Maski. In the upper Sub-phase the dominant ware is the brown-and-black ware, the pale grey ware being very much in subordination. A few painted sherds with violet and purple paintings on a dull red slip are also found.

The stone axe industry is the highly developed industry of this Phase in close association with a rich microlithic industry which weakens as it approaches the upper sub-phase. This rich urban microlithic phase is characterised by parallel-sided blades with steep blunting on one side and blades with serrated edges showing fine polish, with a few lunates. On the basis of parallel-sided blade industry, Phase II corresponds to the Brahmagiri chalcolithic Phase I, even though the painted pottery makes its appearance at a late stage of Phase II.

4. Relationship and Chronology of Central and Western Indian Chalcolithic) Neolithic Culture

Despite local variations, the (chalcolithic) Neolithic culture of Central and Western India, (nurtured in the black cotton soil), as far down as Brahmagiri, is broadly homogeneous in its content. In the southern Deccan sites, Brahmagiri, Sanganakallu, Kallur and Maski, it is dominated by a local neolithic industry characterised by the polished stone axe trait, while in the northern Deccan and Central Indian sites, Sojanipur, Nagda, Maheshwar, Navdatoli, Bahal, Prakash, Nasik, Jorwe, Nevasa, etc., it is distinguished by a profusion of painted pottery ; however, a microlithic industry of parallel-sided blades and polished axes, as at Nevasa, and burial urns as at Bahal and Jorwe, link both these regions and a two way traffic is thus discernible.

The tradition of painted pottery and copper-bronze celts and the ribbon flakes of this culture are closely parallel to those of the Harappan culture in Kathiawar ; but the notable correspondence between the two cultures is confined to (a) dishes-on-stand, handled sauce-pans and the carinated bowls which occur in the post-Harappan levels at Rangpur, (Lothal ?) and Somnath and at the (chalcolithic) Neolithic sites of Maheshwar and Prakash and (b) to a double pot obtained from Jorwe which is analogous to a similar pot from Kot-Diji in Sind. All these serve to underline the links between the Harappa culture and the (chalcolithic) Neolithic culture of Central and Western India.

The most remarkable evidence that links up the Central and Western Indian chaloclithic sites with the post-Harappan sites of Kathiawar and the chalcolithic sites of the Indus Valley is the recurrence of a common flaking tradition of the parallel-sided blade industry in the Karnatak, Western India, Western Pakistan and further westward in 'Western Asia and the Aegean. This is the technique of crested-guiding-ridge-flaking, the one employed for the mass production of blades.

The classic site where such flakes and fluted cores are found is Le Grand Presigny in France. This technique is observed in the Aegean, in Turkey and in the lower Indus region. At Le Grand Presigny this long blade industry did not reach its zenith until the end of the neolithic times. In the Aegean at Melos this industry belongs to the Pre-Mycenean period. In Turkey it occurs from the middle chalcolithic levels. In the Fertile Crescent it comes from the neolithic levels of Jericho, Jerash and Makertu.

In India the Proto-historic (chalcolithic) Neolithic cultures adopted this technique for producing the parallel-sided blades in the local lithic industries. The appearance of this technique at a transitional stage between the neolithic and copper-bronze ages is significant as the blade alone (of the earlier series of lithic tools) had a greater utility with the emergence of metal tools.

At Maheshwar, the earlier historical phase, period III, characterised by the black-and-red ware and the N. B. P. Ware with the punch-marked silver coins can be assigned to *circa* 400 to 200 B.C. On the Brahmagiri evidence, the megalithic black-and-red ware has been dated as *circa* 200 B.C. The proto-historic (chalcolithic) Neolithic deposits of IA and IB phases of Brahmagiri are 9 ft. thick. Wheeler has suggested a mean accumulation rate of 3-4 feet occupation soil in two centuries, and, at this rate, one obtains a duration of at least 600 years or 1000 B.C. as the date proposed for the introduction of this culture. But Ghosh felt that it may be even earlier in the case of the chalcolithic culture of Brahmagiri.

Applying the same scale of computation for the 22 feet thick, chalcolithic phase at Nagda, the duration works out to 1500 years, more than double the span, arrived at for the Brahmagiri chalcolithic phase, thus going to the beginning of the 2nd millennium B.C. This would probably be in accord with the evidence at Rangpur as the latest phase there saw the deteriorating Harappan culture transforming itself into the (chalcolithic) Neolithic culture of Central and Western India. This span will also account for the evolution of the parallel-sided blade industry in this region.

In the majority of the (chalcolithic) Neolithic sites of Central and Western India, the dominant parallel-sided blade industry is accompanied by backed blades with crescents and trapezes of the hunting type. This would mean the survival of the earlier microlithic phase that merged into the immigrating urban parallel-sided blade industry of the neolithic phase. The link is shown by the backed blades, as the steep retouch of these blades is borrowed from the earlier microlithic tradition extant in the geometric tools. It is significant that the blunted backed blades are completely absent in the proto-neolithic parallel-sided blade industries and also in the later Harappan and post-Harappan sites in the Indus basin and Kathiawar. In Kathiawar, Rao points out that the crescents in the blade industry of the late Harappan phase have their chords much longer than their counterparts in the mesolithic period. For this technological change in the parallel-sided blade industry of the (chalcolithic) Neolithic culture of Central and Western India one should presume a longer date for the evolution of this culture going back probably to 2000 B.C. All these show that (chalcolithic) Neolithic culture of Central and Western India is an immigrating culture of western origin and is deep-rooted, though 'the skeletal remains are not sufficient to infuse life into the archaeological material'.

5. PROVINCE B—SOUTH INDIA

A distribution map depicting the pointed butt polished axe, characteristic of a neolithic age in India shows the grouping in two clusters, viz. in South India (particularly concentrated in the Karnatak region) and in Eastern India. They are absent in both the coastal regions. From a superficial resemblance of these pointed butt axe in the Karnatak and Eastern India, a north-east to south-west movement has been suggested for the neolithic axe culture. This is further supported by Haimendorf's Munda hypothesis that a late neolithic civilization with eastern affinities and associated with the same form of Austro-Asiatic tongue permeated the older population of Deccan. A further correlation is also shown in tho affinity of the living megalithis culture of Assam with the Gadabas and Bondos of Orissa and the Marias of Baster.

The older stratum of the neolithic age of India may, therefore, be represented by the pointed butt type of stone axe. Since this type is not uniformly distributed in India but is profuse in the Karnatak and in Eastern India with an intermediate regional gap between the Krishna and the Mahanadi basins, we are led to think in terms of two different neolithic provinces—a southern Stone Axe Culture concentrated in the Karnatak and eastern Stone Axe Culture embracing Orissa, Bihar, Bengal and Assam. Climatically also these are two different regions ; the Karnatak area of the Deccan plateau falling in the arid region in the lee of the western ghats with an average rainfal of less then 30 inches and an eastern monsoon zone having an average rainfall of 50 inches in Bihar, 60 inches in Orissa and Bengal and more than 100 inches in Assam. Besides, the neolithic sites in both the regions are confined to the plateaus and are found very rarely in the alluvial flats. The reason for the detached distribution of the pointed butt axes in the Eastern half of India appears to be ecological.

NEOLITHIC IN THE KARNATAK

The largest collections of Neolithic artefacts from the surface were made in Bellary District by Bruce Foote, Richards, Knox, Jardine and Gompertz.

Allchin drew up a complete picture of the Neolithic Stone Industry of the north Karnatak region from a typological study of all the early collections. He made out three basic stone working techniques, flaking, pecking and grinding and found that pecking was rarely employed for edge-tools. While it was more common among rubbers and grinders it was restricted to certain sizes of celts. Similarly over-all grinding was reserved for a few small and well-shaped axes. He pointed out that there was no clear evidence of any evolution in the application of these techniques in this region and that they were known from the earliest neolithic settlements. He said that in all probability they were derived from the neolithic stone working techniques of the Middle East and Iran. In the range of tools is included axes, adzes, chopping tools, chisels, wedges, scrapers, points, rubbers and grinders, hammer stones and mace-heeds. On the other hand excavations at Brahmagiri by Wheeler followed at Sanganakallu by Subbarao both in northern Mysore, showed a Neolithic Axe Culture at Bellary evolving from a proto-neolithic phase to a highly developed neolithic phase in stratigraphic sequence and in accordance with the surface evidence of Allchin.

The next largest collection of polished axes further south comes from Shevroy hills in Salem District where also as at Bellary there are large dykes of basalt that provided the requisite raw material for the polished axe culture. A few celts have been collected beyond Salem. The total absence of celts in the region south of the Kaveri should be attributed to the extreme rarity of basaltic dykes.

At Brahmagiri, phase IA yielded one complete small flat axe with roughly parallel sides which converge abruptly to a pointed butt, three broken axes, besides several chips and flakes and these are continued even in the lower levels of the succeeding Sub-period IB, with the pointed butt type of celt, thus clearly showing that Brahmagiri was a factory site, the centre of a local industry. Whether IA represents a true neolithic culture remains to be decided. Copper was introduced in such small quantities into this Polished Axe Culture that it was ineffective in changing the main neolithic culture, economically and technologically. In the proto-historic culture of Central and Western India, a flat copper celt is an ubiquitous feature. The occurrence of a flat copper celt in the mid-level of IB at Brahmagiri and the unique polished flat axe in stone, lower still in IA can only show copying in stone of the copper flat celt already familiar in this phase. A similar axe is reported by Foote in the Shevroy hills further south. If it is so, we can expect the extension of the (chalcolithic) Neolithic culture as far down as Salem.

At Sanganakallu, Subbarao came across certain stages demonstrably earlier than those represented at Brahmagiri. The earliest occupation at Sanganakallu, Phase I, is separated from the succeeding Phase II by a thin barren layer. The former is characterised by the presence of heavily patinated flakes of trap and sandstone with a crude microlithic industry of quartz and chert without any evidence of pottery. The patinated flakes are long and thick, with plain striking platforms showing Levallois technique. Seshadri believes that there is a microlithic flake industry of jasper, flint and chert found on the surface at Brahmagiri which, however, has not been traced in the excavations. This surface group, styled Pre-I phase of Brahmagiri, appears to have preceded Phase IA of Brahmagiri excavations and even resembled the flake industry of Phase I of Sanganakallu.

Thus, this industry represents the earliest Polished Axe Culture at Sanganakallu and Brahmagiri, and seems to lead to the regular neolithic industry characterised by grinding and polishing of the implements in Karnatak. Subbarao thinks that the thin butted axe with a convex cutting edge, sides rounded abruptly to meet the faces of the axes and flat pointed oval section may be one of the earliest of the Bellary Neolithic Axes having their origin in phase I since the flakes in Phase II have their proto-types in Phase I.

Phase II, characterised by fresh stone axes and a fine microlithic industry, is divided into two horizons on the basis of relative distribution of two main fabrics of hand made pottery, the pale grey ware in the lower and a coarse brown and black ware in the upper Sub-phase. The microlithic industry is more in evidence in the lower Sub-phase. It may be described as an industry characterised by parallel-sided blades, parallel-sided blunted blades and lunates of chert and jasper, a mixture of the chalcolithic urban type and the hunting type of an earlier microlithic industry.

This phase shows the neolithic polished axe industry in various stages of manufacture and in a variety of shapes of axes, pounders, polishers, sling stone and chisels. Since the lower levels of Brahmagiri I and derivatively Sanganakallu upper Sub-phase of phase II are ascribed to 1000 B.C., the earlier sub-phase of phase II and phase I at Sanganakallu must be far anterior to 1000 B.C. This is especially the case with the latter, in view of the intervening sterile layer.

The Karnatak Polished Axe Culture complex is to be deemed a local industry developed on the soil as it emanates from a crude post-Palaeolithic (microlithic) flake industry of the hunting stage when axes were rare. This in turn develops into a rich stone axe industry absorbing a dominant parallel-sided blade industry coming from the proto-historic chalcolithic industry of Central and Western India. Such a complex is essentially different from the Eastern Stone Axe Culture complex which is devoid of any association with microliths. The Eastern Stone Axe Culture can only be derived from a South East Asian source. If there is to be a western origin for the Southern Stone Axe Culture, it could have been only prior to the introduction of the proto-historic (chalcolithic) Neolithic Culture of Central and Western India which brought in the urban phase of the microlithic industry about 1000 B.C. from Kathiawar. If we assume that the stone axes in the Indus valley are contemporaneous with Indus Valley Civilization, a reasonable date thereof would be 2500 to 1500 B.C. Prior to 1500 B.C. there was a dominant microlithic industry of the hunting stage all over Western and Central India. The very region—the Deccan Trap—which would have supplied ample material for the polished axe industry of the Indus Valley type has not, strangely enough, disclosed any trace of such an industry. On the other hand, we have evidence of an entirely different industry, viz. that of the post-Harappan crested guiding flaking technique which is indeed the characteristic of the West Asian neolithic industry. Hence the origin of the polished axe culture of the Karnatak should not be looked for in the Indus Valley or in the Middle East and Iran as conjectured by Allchin. The all-eastern origin suggested by Worman on typological grounds does not also seem to be tenable for the reasons that it is uninfluenced by the microlithic industry at any stage and that the Eastern Complex is quite different from the south Indian which is characterised only by the pointed butt axe and its variations. The Stone Axe Culture of Bellary, then, should have come on the scene autochthonously round about 2000 B.C.

Neolithically, the island of Ceylon was a cultural back-water where the true microlithic phase, as in the tip of the peninsula has persisted for a very long time and remained uninfluenced by the polished neolithic axe of Southern, Eastern and Western provinces of India. The Balagonda Neolithic phase of Ceylon found in rock-shelters is an independent cultural phase, characterised by pitted macroliths called Balagonda celts ground and polished, along with anvils and grind-stones and a few microlithic tools of the Bandarawelian facies.

6. PROVINCE C—EASTERN INDIA

The Eastern Indian Neolithic complex can be grouped into the Assam Culture complex and the Bengal-Bihar-Orissa Culture complex and the analysis presented below is mainly that of Dani who made a systematic study of all available material from Eastern India and South-East Asia. Since the classification of neolithic celt types in India and South East Asia by Worman is hard to reconcile with the actual tools known, it is purely of academic and theoretical interest.

ASSAM CULTURE COMPLEX

The neolithic cultures of Assam follow a pattern dictated by geographical factors and they can be best studied on a regional basis as each group of tools of a particular region shows a distinct kinship in material and form. The technique of manufacture is common to all these regions, though the forms show variation from region to region. As the material was obtained generally in the form of flat slabs from stream beds, very little chipping or flaking is necessary. Battering or hammering and grinding or smoothing are sufficient to produce the tools found.

The neolithic culture of Assam falls into six zones:—

1. *Sadiya Frontier.*—Chief Material—Jadeite, less typological variation than in Cachar hills. Main types show affinity with ground tools from Yunnan, also the nearest source of jadeite.

2. *Naga hills.*—Chief material gneiss, varied and distinctive tool types. Besides the common types found all over Assam we have here the gouge adze found abundantly in Burma, Malaya, Siam, Laos, Cambodia along with tanged axe and the wedge blade special to this region.

3-5. *Khasi, Garo and Cachar hills.*—Most of the types seem to be derived from Cachar Hills and remarkably similar to the developed tools of upper Burma.

6. *Brahmaputra Valley.*—Mostly from Tezpur District. Material sandstone. Tools made of smoothed pebbles.

Assam types: Faceted hoe: rectangular cross section, common tool in Assam, Chittagong, Yunnan and South-east Asia where it is known as "Quadrangular Adze". Three stages are involved here: (a) primary one for rough out ; (b) secondary one for producing the normal hoe and (c) tertiary one for producing the median cutting edge. Five varieties of hoes are noted in Assam :

1. curvilinear ;
2. bifacially ground median edge type ;
3. unifacially ground edge type ;
4. feceted tool with side notches found only in Naga hill ;
5. long type with parallel sides.

None of these types was mentioned by Worman in his generalised classification of celt types.

Shouldered hoe: "Spade-shaped celt"—Though similar to the faceted hoe, the main variation consists in the prolonging of the butt into a tenon for better hafting. In some, corners are right-angled by a process of wire-cutting or sawing ; in others, the angle is obtuse or even curved at the junction, both ranging in lengths from 6 to 14 cms. The regular rectilinear variety is confined to Naga and Cachar hills where it appears to be derived from Burma. The irregular (curvilinear) variety on the other hand is restricted to the Brahmaputra Valley, Khasi and Garo hills where it appears to be the local imitation of the regular (rectilinear) variety found in Naga and Cachar hills. The curvilinear specimens show ovoid transverse sections and the rectilinear ones show rectangular sections. Here also five varieties are recognized. They are found all over Assam except in Sadiya Frontier.

While chipping and pecking can be seen in curvilinear ones, the rectilinear ones show high smoothing. The distribution of shouldered hoe is confined to Eastern India, Burma, Indo-China and other parts of South East Asia. The rectilinear type alone shows a sporadic distribution in India. This type was found by Ball in Dalbhum and Baidyapur in Mayurbhanj, by Rivet Carnac in Central India, by Cammiade near Godavari river mouth, by Heimendorf in Hyderabad and by Worman in Northern Mysore.

3. *Splayed Axe*: Rare in Assam, found in only one variety, bifacial median splayed cutting edge with concave sides terminating in a narrow flat butt. Transverse section nearly rectangular. The majority of these tools are completely smoothed and highly polished. Their lengths vary from 7 to 13 cms. and the distribution is confined to Eastern India and South East Asia. It is from the metal type that the stone examples appear to have been copied. This is the most highly developed form of all in India and the distribution definitely indicates that the stone examples are the most recent arrivals in India from the East.

4. *Rounded butt type*: ("Round axe" of Heine Geldern)—A long thin axe, oval to lenticular in section with rounded butt cutting edge convex, unifacial, found in different stages of pecking, chipping and smoothing, in Garo hills and rare in the Naga hills. Lengths range from 20 to 25 cms.

5. *Axe with broad cutting edge*: A variant of the above one, cutting edge being very broad, while the sides taper very acutely. This corresponds to Pakrasi's new find in the Garo and Sarania hills in Assam.

6. & 7. *Tanged axe and wedge blade*: They are a distinct group by themselves, found mainly in the Naga hills and also in upper Burma. The former type, with slight shoulders at the butt probably influenced by shouldered hoe but different by their bifacial cutting edge and the rounding of the butt. A few occur at Mayurbhanj in Orissa.

8. *The grooved Hammer-stone*: Occurs at Bisnath in Tezpur District. It is not found anywhere else in Assam or in South East Asia, except Annam. A few examples come from China.

The first three types—the faceted hoe, the shouldered hoe and the splayed axe have a wide distribution in South East Asia and South China and the Assam specimens belong to this general complex. The problem of their origin and age is therefore linked up with the existence of these types in all these countries. The tanged axes and wedge blades are peculiar to Naga hills.

BENGAL-BIHAR-ORISSA CULTURE COMPLEX

Falls into three zones: (1) Chittagong region, south of the Khasi, Garo and Naga hills of the Assam Culture Complex: (2) Sub-montane zone of the Himalayas and (3) the Chhota-Nagpur plateau.

1. *The Chittagong hill zone.*—This is culturally related to Assam Complex since the few tools found here are of the faceted tool variety of Assam.

2. *The sub-montane zone of the Himalayas.*—Very few tools are found on the hill terraces and slopes of the higher region in Darjeeling. They are absent in the recent alluvium of the plains. The tool varieties include faceted tool types, rounded butt axe, wedge shaped axe as in Assam besides chisels and hammer stones.

3. *The Chhota-Nagpur plateau* (West Bengal and Orissan high lands). The material found here falls into two groups—(a) Types found under observed conditions such as those of Anderson in the valley of Sanjai below the alluvium, Sen in Sanjai Valley, and Bamal in Midnapore District, Ray in the terraces in Bongara in Manbhum, Sinha in South Manbhum, Lal at Ban-Asuria, Jashpur, Daspalla and Baidyapur in Orissa, Mukherji at Deulbarh in Midnapore District and Nagar in Musanagar in Kanpur District.

Besides Neoliths, there appears to be a chalcolithic facies in the neolithic complex of this region. In Southern Bihar the majority of the microlithic sites are associated with the copper belt which starts five miles north of Chakradharpur and runs through Kharsawan and Seraikela across Dhalbhum through Rakha mines to Ghatsila on the Subarnarekha. Gordon says that copper slag heaps and micloliths are in close proximity and that the presence of microlithic sites from Chakradharpur to Ghatsila including Talsa, Banabassa and Rakha mines, coincides so closely with the copper seam that it is difficult to suppose that they were not associated. It is interesting to note that in Mayurbhanj in Northern Orissa there are no microlithic sites and in fact, once away from the copper seam, no microliths are to be found. Further the pointed butt neolithic axes found at Talsa and Chandabura on the copper seam are probably part of a (chalcolithic) Neolithic culture.

Sen and Ray found a non-geometric parallel-sided blade industry in Sanjai Valley adjoining a neolithic site at Chakradharpur and Bongara in Manbhum. Few blades showed blunted back and curved back types. There are a few geometric shapes like lunates, semi-lunates and trapezes and fluted cores. There is no pottery or copper tools or slags associated with these microliths. Yet the appearance of the ribbon flake-blades (reminiscent of the Harappan tradition in Central and Western India) side by side with the earlier hunting types (commonly seen in the Singrauli Basin near Mirzapur or in the easternmost microlithic site of Birbhanpur in West Bengal) would still point to some connection with the proto-historic chalcolithic phase of Western and Central India. Can the Tripuri Industry at Jabbalpur, west of Bihar, be considered as a link connecting Western India and Chhota Nagpur plateau?

The typology of the neolithic tools shows the following verieties: (1) axes; (2) wedges; (3) chisels; (4) perforated tools; (5) shouldered hoes and (6) hammer stones. Three different techinques—chipping, pecking or hammering and grinding have been used either singly or in combination to produce these tools.

The predominant tool in this culture complex found in Singhbhum and Manbhum is the rounded butt axe with median cutting edge bifacially ground and the transverse section ovoid or lenticular. This type is found in Assam, and also in Kaimur and Banda.

Wedge shaped axe.—A variant of the axe, the main difference being the pointed butt end chipped transversely and ground, producing a flat butt.

Chisel.—Generally rectangular in cross section with flat butt, cutting edge (occasionally splayed) bifacially and unifacially ground. This tool is reported by Sen in Singhbhum in Bihar and by Mitra in Jaugada in Southern Orissa.

Shouldered celts.—As in Assam, it is found at Deulbarh in Midnapore District, at Bongara in Manbhum, Dalbhum, Mayurbhanj, Central India, at the mouth of Godavari, Hyderbad and Northern Mysore.

Perforated stones.—Circular or oval flat stones with a hole in the centre, worked from both faces, hardly any grinding, edges blunt.

Hammerstones or Pounders.—These are generally elongated pebbles hardly showing any working. Ray reports a potter's dabber from Bongara in Manbhum and outside this region, a number of grooved hammerstones are found in the Kaimur hills.

(b) A few new types have been found from chance surface collections of Bodding, Ray and others. The 'Bar chisel' is one such reported by Lal at Ban Asuria, Jashpur, Thakurani, Sitabhanji and Daspalla in Orissa and in the Santal Parghanas in Bihar. It bears close similarity to the Malayan types with the main difference that the Malayan types are ground.

There is a thin-sectioned broad axe from the Santal Parganas which is abundantly met with in the Garo hills in Assam. The faceted tool, the shouldered hoe and splayed axe so well known in South East Asia, came to India much later as they are found sporadically without archaeological context. The occurrence of the shouldered hoe inside the fortifications of Kausambi, Sisupalgarh and Rajgir is highly suggestive of a very late intrusion.

This is to a certain extent corroborated by the absence of these types in the first group of neolithic types of the Bengal-Bihar-Orissa Culture Complex, specially characterised by the rounded butt axe simulating the pointed butt axes of the peninsular India. The sporadic nature of these specialised tools in India further suggests that they may better be regarded as imports, or at best, local imitations of foreign types rather than the products of a separate and distinct cultural grouping in India.

7. THE CULTURAL IMPACT FROM THE FAR-EAST

Burma.—The neolithic celts, all unassociated surface finds, as in Assam, are restricted to the hilly region of Arakan and Tenasserim. They fall into three classes, as in Siam, Malaya and Indo-China: (1) chipped tools; (2) edge-ground tools; and (3) completely ground tools. The chipped tools inherit the palaeolithic chipping technique. The ground tools include faceted tools, shouldered hoe, tanged axe, splayed axe, wedge, chisels gouge, gouge-adze, ringstones and hammer-stone.

Siam.—The adjoining region of Siam is not so much explored as Burma and Indo-China, but still three archaeological stages are recognised: (1) a top layer of Buddhist period, (2) an intermediate layer of pottery with cord-marked design similar to those of and probably imported from late Prehistoric Indo-China and (3) the lowest layer yielding archaic stone tools like axes, points and scrapers resembling the earliest Bacsonian and Hoabinhian cultures. The surface tools without archaeological context to be equated with the intermediate layer here include the faceted tool, splayed axe, gouge adze and hammerstones resembling those of Malaya and Indo-China.

Malaya.—The Neolithic culture of Malaya is also without archaeological context; but the types are very similar to those of Indo-China. A tentative sequence has however been attempted by consideration of depth in the Cave culture of Kelantan. The lowest layer contained Hoabinhian choppers, ovoid implements chipped on one or both sides but pottery was absent. The intermediate layer contained finer Hoabinhian-like oval implements, short axes, small flake-scrapers together with chipped and partly smoothed celts ; and pottery was rare. The uppermost level contained angular celts with rectangular cross section, chipped and smoothed over. Black or reddish pottery with cord-marked or incised varieties similar to those from Burma and Indo-China also occurred. Many vessels have markedly angular designs and the forms of decoration suggest metallic inspiration in their designs. Hence Malayan Neolithic pottery is a late descendant of the cord-ornamented ware group known from China in the Chou period (1122-255 B.C.). The late tools are (1) the faceted tool, predominant in Malaya and Siam and rare in Burma and India, (2) the shouldered hoe both regular and irregular varieties, (3) the round axe with a cylindrical butt which is typologically different from the Indian pointed butt type, (4) the splayed axe in two varieties (a) common type found in Assam and Far-East, and (b) the one with slightly tapering side and slightly tapering cutting edge so far confined to Malaya and Siam, (5) gouge Adze (pick adze or beaked adze) known in Siam, Burma, Haut-Laos and rarely in Assam, Burma and Cochin-China, (6) gouge known in Burma and Indo-China, and (7) chisel, completely ground with unifacially ground cutting edge, one variety of which is the bar-celt known only in Malaya and parts of Bihar, Orissa and the Chhota-Nagpur plateau. The other types peculiar to Malaya are the waisted axe and the knives.

Indo-China.—The Key to the Neolithic problem in Eastern India and the whole of South-east Asia is found in Indo-China. The evidence comes from cave shelters and kitchen middens. Three cultural divisions are recognised in Indo-China, viz. Hoabinhian, Bacsonian and Somrogsen cultures, with a typological evolution from crudely chipped and slightly smoothed stone tools found at the base of the deposits to well-shaped finely-smoothed stone artefacts at the top. Pottery occurs only at the upper levels with the more advanced tool-types like the shouldered hoe and faceted tools exhibiting a sawing technique. Hoabinhian and Bacsonian have three divisions which can be equated to one another. The Somrongsen kitchen-midden culture of Cambodia and Annam is contemporary with the final Bacsonian and Hoabinhian stages and the types are most varied and highly developed ground tools. Along with the types of the two earlier phases, the following types are very characteristic—the shouldered hoe, the axe and the faceted tools with unifacial and bifacial ground edge, adze with bevelled cutting edge, chisels and gouges. Iron and bronze implements are also associated. Pottery is hand-made with sophisticated designs.

8. RELATIONSHIP AND CHRONOLOGY OF THE STONE AXE CULTURE OF EASTERN INDIA AND S. E. ASIA

In Eastern India and all over South East Asia, two different manufacturing tool traditions persisted side by side, unaffected by microlithic (mesolithic) phase in contrast to what was noticed in the neolithic provinces A and B. The first tradition, using predominantly chipped and flaked stone tools reminiscent of a palaeolithic period was the earlier one which was uniformly distributed all over this heavy monsoon region. Further, edge-grinding was a consistent feature of the flaked and chipped tools in the Far East, wherein we can see an intermingling of the two traditions in the Hoabinhian and Bacsonian in Indo-China and Kelantan in Malaya. This was the main cultural tradition of the Early Eastern Neolithic complex, prior to the appearance of an independent second tradition belonging to the later Eastern Neolithic Complex using predominantly ground, sawn and fully smoothed tools.

The second tradition gains in importance as we proceed eastward from Chhota-Nagpur to Indo-China through Assam and Burma. The heart of this culture can be located in Malaya and Indo-China. Further, this tradition of grinding and sawing tools is associated with pottery in South East Asia, suggesting an intrusion from outside. The Somrongsen culture characterized by the later tradition in Indo-China indicates a link with the Hong Hong culture of South East China and shows similarities with Malaya.

Laos, Yunnan and Burma show typological similarities to Somrongsen and Malayan cultures, yet there are differences. The shouldered hoe and gouge-adzes are absent from Yunnan, but they link Laos and Burma with Malaya and Siam.

In South East Asia, there is a distinct grouping of tools in the later phase and a single type of tool such as the shouldered hoe cannot be torn of its context and attributed to the 'Austro-Asiatics', speaking the Mon-khmer group of languages. One variety of chisel, viz. *Bar-chisel* or adze is particularly characteristic of the later tool types of Malaya. Noone has suggested that these might have been used as ploughshares especially as they are often found "unfinished", i.e. flaked but not ground. It recurs only in Eastern India in the hilly tracts of Southern Bihar, West Bengal and Northern Orissa in the same complex as it is found in Malaya. On this evidence, a maritime communication seems likely. In the copper hoard site of Gungeria in Madhya Pradesh and in the Gangetic basin, the bar-celt, the shouldered hoe, the splayed axe, and the long rectangular chisel are found together. They appear to have been copied from stone celts of similar shapes occuring in this region. There is, therefore, good reason to believe that the copper-hoard complex developed from their prototypes in stone, in quick succession when metal began to replace stone. In the Gangetic basin, Lal observed an ill-fired, thick ochre washed pottery as a likely associate of the copper tools and if it is to be equated with that at Hastinapur lying below the painted grey ware, it follows that the copper-hoards of the gengetic basin could be pre-Aryan assignable to about 1500 B.C.

At present, the tract covered by the copper hoards and the stone bar-celt complex is mainly occupied by the Mundas, Santals and other tribes belonging to the Proto-Austroloid group whom the Vedic Aryans called the *Nishadas*—a people of dark complexion short stature and short nose (*anas*). They are probably the authors of the Early Eastern Neolithic complex, characterised by the chipped, flaked and ground celts that were found 'in situ' in the first two stages of Hoabinhian, Bacsonian and Kelantan cultures in S. E. Asia. Certainly, this early dating will not hold good for the developed later Eastern Neolithic complex, in which a sawing technique, using a metallic wire and abrasive is involved in the square-cut faceted tool and in right angled shouldered hoes. The archaeological evidence posed by Mishra at Sonepur in Bihar would bring the Later Eastern Neolithic Complex to the period of the N. B. P. Ware of India which is also in consonance with the dating of the later phase in South-East Asia, where the complex is 'in situ'.

The earliest evidence of the shouldered hoe in bronze comes from Anyang in Hupei, from the burials of the Yin dynasty (1300 to 1026 B.C.). A few stone specimens outside the graves come from Honan and from this cultural area of China, comes the faceted square-cut axe which has been obtained from a context where metal has been in use. The infiltration of these northern Chinese Culture into the Southern countries is known in Szechwan and Fukien. There is no doubt that it penetrated further south, into South-East Asia where it is recognised as the developed Neolithic culture. It follows that the appearance of metallic tradition in South East Asia can hardly be earlier than the one at Anyang. On the other hand, the evidence from Hongkong, Somrongsen and Malaya indicates a date somewhere about the second half of the first millennium B.C. for its existence in these regions. The persistence of this tradition even when iron and bronze were introduced is known from Malaya and Indo-China. At Kelantan in Malaya, the later group of ground tools with pottery lay under a complex in which Chinese glazed ware was found. A clue is given by the find of a few sherds of a typical highly polished black ware (said to be "Greek or Attic") in the upper levels of the Kelantan sequence, dated between 4th to 2nd centuries B.C. Dani says that its date may even come down to 1st or 2nd centuries A.D. if it is of the same type found at Arikamedu in India.

With the discovery of the N. B. P. Ware in Northern India, it is not necessary to seek a similarity for this highly polished black ware of Kelantan at Arikamedu. The shouldered type of hoe has been found in Kausambi, Rajgir, Tamluk and Sisupalgarh where N. B. P. Ware is coeval and since we have shown a maritime influence in the later Neolithic Period between South East Asia, Orissa and Bihar, this black pottery of Kelantan is likely to be homologous with the N. B. P. Ware of India. At Jaugada in Southern Orissa, Mitra found a neolithic industry in a sandy layer seemingly associated with black-and-red ware below an iron using culture. The neolithic industry is characterised by a rounded butt axe with a straight cutting edge and two rectangular chisels with quadrangular section. Bose found a similar Eastern straight sided axe at Mayurbhanj. Sen found a rectangular chisel at Bamal in Midnapore District, a bar celt-like tool and a "screw-driver" type chisel (unique in India) at Singhbhum. The seeming association of Eastern Neolithic type of axes with black-and-red ware at Jaugada has been confirmed beyond doubt at Sonepur in Bihar, by Mishra who points out that this is the first reported occurrence of this ware in this region. Mishra brings to light a few polished Neolithic stone celts in Period III (650—450 B.C.) at Sonepur in Bihar. The types of axes are (1) a tiny celt, a rounded butt type with thin lenticular section and a rectangular adze with quadrangular section. The associated pottery is a fully evolved N. B. P. Ware with a black-and-red ware and iron. It is further presumed by the excavator that the neolithic axes should have been re-used and that they were present even in the earlier period (1000—650 B.C.) characterised by a black-and-red ware and the N. B. P. Ware. The stone celts persist also in the succeeding periods IV and V (450-50 B.C.) when, both the N. B. P. and black-and-red ware flourish with the punch-marked coins in the latest phase. The find of a neolithic axe at Vaisali by Krishna Dev can also be attributed to this period. Thus in Eastern India we have an undoubted association of the N. B. P. and the black-and-red ware with the Late Neolithic complex of South East Asia. This phase persisted even after iron and punch-marked coins were introduced. This is also the case in Malaya and Indo-China.

Since the copper hoards of the Gangetic basin come in close succession to the Later Neolithic complex in Eastern India, it may be that the pottery associated with the copper hoards is the N. B. P. and black-and-red wares rather than an ochre-washed ware. But then the evidence from Bahadarabad, as suggested by Lal, cannot altogether be ignored.

9. PROVINCE D—KASHMIR

Outside the Deccan and Eastern India and unconnected with both we have a neolithic site at Burzahom in Kashmir where the pointed butt axes with hand-made buff and grey ware were found by De Terra in a post-glacial loess, 9 feet deep. This industry was succeeded by the post-Harappan Jhangar culture characterised by a black polished ware and sherds with incised geometric design. Gordon would identify the black polished ware as N. B. P. Ware. As the ceramic types of the stone axe and Jhangar phases have not been properly identified, the nine feet depth of the unweathered loess deposit in the lowest Jhelum terrace as also the association of the axes with waste flakes and cores reminiscent of a late Sohan technique and even to a Proto-neolithic phase characterised by microliths of jasper and flint from the Potwar loess surface at Uchali, would take the antiquity of the Northern Neolithic industry at Kashmir far beyond that of the Mesopotamian which has been ascribed to the period 6000 to 4000 B.C.

Can it be that the neolithic phase of Kile II of Kile Gul Mohamad assigned to the 4th millennium B.C. in Baluchistan has inspired the loessic Neolithic industry of Kashmir? Between Baluchistan and Kashmir, the only neolithic pointed butt axe comes from a site on the banks of the Indus opposite Shadipur near Attock. The rest of the Neolithic celts found at Harappa and Mohenjodaro and at Nal in Baluchistan definitely occurred in metal age levels. Thus the North Indian polished Stone Axe Culture (clearly preceding) the Jhangar phase of the Indus Civilization can be much earlier than the Southern Karnatak Neolithic Culture and apparently not influenced by the Eastern Indian Neolithic Culture.

10. EPILOGUE

Summing up the facts stated above, we have in India, a neolithic pattern showing four types of regional Neolithic Cultures which may be designated A, B, C and D. The Neolithic culture A is chalcolithic in character and is restricted to western Madhya Pradesh and Western India co-extensive with the Deccan trap region. This complex is characterised by parallel-sided ribbon flake blades, painted pottery and copper artefacts of post-Harappan facies of Western origin. As it comes closer to the Karnatak region in the South it absorbs the polished stone axes of the second Neolithic Culture B spread all over the South. The urban parallel-blade industry is further galvanised by the earlier hunting type of microlithic phase, characterised by the lunates and trapezes with steep re-touch, which was changing itself into the neolithic as we have seen at Gujarat. This galvanisation has become very patent in the blunted backed blades, that persist side by side with ribbon flakes, as it cannot be explained in any other manner. It is interesting to note that such an impact did not take place in the later Harappan sites of the Kathiawar peninsula, just outside the (chalcolithic) Neolithic cultural regions of Central and Western India.

The Neolithic Culture B is centred in Karnatak in South India away from the Deccan trap region. It is characterised by the pointed butt type of axe which apparently originated in the region itself. In its earlier phase, it is related to the post-palaeolithic flaking technique, arising in a microlithic milieu. Latterly it absorbed the post-Harappan ribbon flake and the painted pottery and copper celt traits of Culture A.

Culture C is restricted to Eastern India where we see three phases overlapping each other. The earliest phase is the rounded butt axe showing chipping, grinding and polishing. It does not show any relationship with the pre-existing microlithic culture of the region as in the Karnatak and in Central and Western India. The second phase is characterised by faceted and square-cut tools involving a metallic technique of manufacture. Closely linked with this is the third phase of the copper hoards of the Gangetic basin and of Gungeria in Madhya Pradesh with tools similar to the types of the second phase. The origin of the first two phases has to be located in the South East Asia in Indo-China and Malaya in real archaeological complexes. The first phase shows a very great antiquity in South East Asia and therefore the rounded butt type of axe has spread uniformly from South East Asia, to Chhota-Nagpur. The second phase characterised by faceted square-cut tools shows an irregular distribution in Eastern India. In Assam we have the faceted tools of Malaya along with the shouldered hoe. In Bengal-Bihar-and-Orissa, the faceted type of tool is absent, but the shouldered hoe, the bar-celt and the rectangular chisel with quadrangular section are similar to those of Malaya thus showing a maritime influence and even indicating the introduction into India of the plough for rice cultivation. This phase was closely followed by the copper hoards of the Gangetic basin and Gungeria which exhibit, in metal, the same type of tools as in stone (including the bar-celt found in Chhota-Nagpur. This phase seems to have come as a second wave round about 4th century B.C. when N. B. P. and black-and-red wares were well established in India and therefore this wave is post-Aryan. Province C has not materially affected Province B in the South except for the sporadic distribution of the regular shouldered hoe in a few places in the South.

The picture I have outlined is largely speculative and the most that I hope for is that it will ultimately stimulate discussion. But one thing is clear that without being unduly influenced by a *'mirage orientale'* for the neolithic origin of India as stated by Worman in 1949 we have evolved our own Neolithic Pattern of India, partly influenced by a West Asian neolithic culture, partly by the Harappan Culture, partly by the Far Eastern *neolithic* culture and partly of autochthonous origin. Further excavations in the four different regions and especially in Eastern India will make us understand better the new pattern that is beginning to appear as a result of the brilliant work done by Sankalia, Subbarao, Sen, Ray and the officers of the Union Department of Archaeology and the admirable contribution by Dani in East Pakistan.

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SECTION OF MEDICAL AND VETERINARY SCIENCES

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PRESIDENTIAL ADDRESS

THE PLACE OF VETERINARY RESEARCH IN THE NATION'S PLAN FOR FOOD PRODUCTION

Friends! I am deeply conscious of the great honour you have done me in electing me as president of the Section of Medical and Veterinary Sciences for the 46th session of the Indian Science Congress. I have little scientific attainment to my credit to occupy this position, but your appreciation in this manner of the close ties that exist between Medical and Veterinary Sciences is no small source of pleasure and satisfaction to me and the profession to which I belong.

The subject that I have chosen for my address does not represent any specialised branch of study in the field of medical or veterinary science, but serves to focus our much-needed attention on the role of veterinary research in food production—a problem of no small magnitude.

Our country today is passing through a period of great and varied activities for the achievement of the various targets laid down in our national plan for community development. How to improve the lot of our poor masses and to provide them with food, shelter and a decent living is the problem engaging the attention of our leaders in the political and scientific fields. While the leadership and popular support which must at all stages be available in the execution of our plans is there, it is the science and technology in all spheres which must form the spearhead of our struggle for the achievement of freedom from want and hunger.

Agricultural production is supposed to be the core of the second plan and this must remain so till the period the country attains self-sufficiency in the matter of food. Unlike some advanced western countries, animal husbandry is looked upon as the basis of Indian agriculture and the husbanding of our animal resources when well-developed can contribute materially to the well-being of our people. Our food problem today is the problem of all problems and how the application of veterinary research to solution of this problem in the country can materially strengthen our existing food resources is the theme of the present address.

LIVESTOCK AS THE NATIONAL WEALTH

India possesses the largest livestock population in the world and some breeds of cattle, buffaloes, sheep and goats possess vast potentialities for development, not only to meet the growing needs of the country, but also to build up a sizeable export trade.

Our animal wealth today in the shape of multiplication of numbers, the animal products for human use, the valuable organic manure and the animal labour for agricultural operations contribute very substantially to the economy of the country. If we make a comparison between certain industrial and agricultural commodities which loom so large in the public mind and our cattle wealth, it would no doubt be a big surprise to some of us that according to the figures available for the year 1954-55, iron, steel and coal, which are so vital to the country and on which so much emphasis is being laid by the Planning Commission, are valued at rupees 85 crores only. On the agricultural side, during the same year, cotton textiles contributed rupees 500 crores, jute rupees 113 crores and sugar rupees 120 crores. Thus the total contribution from these industrial and agricultural commodities amounts to rupees 818 crores which is less than the annual contribution made by valuable organic manure alone which is estimated at rupees 1000 crores.

FACTORS DETERMINING PRODUCTION AND CONSUMPTION OF FOODS OF ANIMAL ORIGIN

Although the population of our country consists mostly of vegetarians subsisting largely on cereals, vegetables and pulses, the tendency towards eating of meat, fish and poultry products is fast growing. In the absence of any reliable data as to the relative proportion of vegetarians and non-vegetarians, the point can, however, be made without any fear of contradiction that there is an appreciable yet unestimated proportion of Indian population that does not object to any type of flesh food. This view finds support in the figures of production and export of meat (1955), indicating that, barring a very small export taken by ships on touching our ports, about 90 per cent of a total annual production of 461,245·2 tons of meat is consumed within the country.

Meat, like any other protein-rich food, is a costly commodity regarded as luxury food, chiefly for the town-dwellers and those who can afford it. One of the many reasons, therefore, why a larger percentage of people representing those belonging to low income group has not taken to meat eating is the somewhat prohibitive cost of this food commodity. The *per capita* consumption of meat and its availability at cheaper cost to a larger section of meat consuming communities would depend upon its production which is closely related to the total livestock population and the quantity of dressed meat obtained from different animals. The general health and the bodily condition of livestock in this country is no more than poor. They are puny, undersized and half-starved due to chronic shortage of feeds and fodders. To crown all these are the numerous killing and chronic diseases which either bring down the number of the different food animals or reduce them to a status of walking skeletons. The average dressed carcase yield, therefore, is very low in India as compared to some progressive meat producing countries of the world.

Regarding milk and the dairy products—another item of food of animal origin—it needs no elaborate statistics to indicate that the position on the production side is very precarious and consequently the *per capita* consumption is very low. According to Agricultural Marketing Survey in India (1957), based on milch cattle and buffalo population figures as given in the Livestock Census 1951, the annual production of milk works out at 468,459,000 maunds. The average availability *per capita* of liquid milk in a population of 356·8 million people according to the 1951 census works out to 5 ounces a day. According to a recommendation of the Nutrition Advisory Committee of the Indian Council of Medical Research, a balanced diet for the Indian population to ensure maintenance of good health must contain, amongst other ingredients of food, 10 ounces of milk daily and this could be attainable only when the total milk production of the country is almost doubled. How can this be achieved? Certainly not by increasing the number of milch animals in the country whose land resources cannot be stretched further to support the ever-increasing human and animal population. If this was ever to be attempted in the face of the ban on cow slaughter, as some of the Gosamvardhan enthusiasts may feel inclined to do, the inherent danger is that this may lead to bankruptcy of the cow, and milk as a saleable commodity may altogether disappear from the market. This foreboding is rightly supported by population figures of milch cows and she-buffaloes in India in the 1945 and 1951 cattle census.

VARIATIONS IN THE NUMBER OF COWS AND SHE-BUFFALOES DURING THE YEAR 1945 AND 1951 AND THE RESULTANT PRODUCTION OF MILK AND MILK PRODUCTS

	1945	1951	Percentage increase or decrease over 1945
Cows (lakhs)	411·01	470·34	+14·4
She-buffaloes (lakhs)	195·72	210·21	+ 7·4
Total ...	606·73	680·55	+12·2
Production of milk (lakh maunds) ...	4682·15	4555·08	– 2·7
Percentage of milk converted to ghee (lakh maunds)	43·3	39·9	– 3·3
Production of ghee (lakh maunds) ...	112·96	103·08	– 8·7

The above table would reveal the information that although during the period from 1945 to 1951 there has been an increase in the combined population of milch cows and she-buffaloes to the extent of 12·2 per cent, the total milk production in the country has gone down by 2·7 per cent. Of the many reasons accounting for this state of affairs is the "progressive increase of the total cattle population of the country without a corresponding increase in the available supplies of fodder and cattle feeds ; this may be said to be the greatest limiting factor for increasing milk yield".

As regards poultry which term includes ducks, geese, turkeys and guinea fowls, the total number stands at 73·9 millions, but the net available market supply stands at 34·23 million birds. Based on total human population, therefore, the annual *per capita* consumption is 0·29 lb., but when the section of population having no objection to taking poultry meat is taken into consideration, the *per capita* consumption comes to 0·97 lb. This, on a statewise distribution and density of poultry population per 100 persons or per square mile, may not represent a true *per capita* consumption rate. The areas having the lowest *per capita* consumption are Saurashtra and Rajasthan where the density of poultry population also stands lowest. The Report on the Marketing of Poultry in India (1955) reveals that in areas where population density is greater, the *per capita* consumption is well over 2·9 lb. indicating that it is the availability more than the customs and the religious prejudices which determine the consumption of any food commodity. In Kashmir, till recently Hindus would not even touch a hen, but of late there has been a steady increase in the consumption of poultry and poultry products, particularly the ducks, as the Kashmir valley provides ideal conditions for duck breeding, and thus the density per 100 persons is quite high. The population density of poultry depends upon various factors of which those which assert most markedly are (i) the epidemics such as those of Ranikhet disease, fowl-pox and the various types of coryza on which little information is available in the country and (ii) the abnormal weather conditions causing high mortality and consequent decrease in the number.

A large percentage of our people have no aversion to taking eggs, and even if there is any religious prejudice to hen's egg, duck eggs are eaten freely without any such prejudice among the Hindus. India produces every year about 33,648 lakh eggs and if they were all put end to end, they would stretch more than three times round the world. In spite of the large poultry and duck population, actual records of the output of individual birds are very scanty. The *Desi* hens are estimated to lay on an average 53 eggs per bird in the course of a year and for the improved birds this has been estimated at 103 eggs. In the case of duck eggs the average output per bird for the whole of India is 90 per annum. Owing to diseases taking a heavy toll of our birds and the fact that producers far removed from the market retain most of their eggs for their own consumption, only about 60 per cent of the hen eggs and 80 per cent of the duck eggs are put on the market. Of these, a substantial proportion is lost to the consumer due to spoilage on account of bad weather conditions.

On the basis of total human population, the egg consumption *per capita* works out at 8 eggs per annum. When compared with the *per capita* consumption in the United States of America or Canada, the position is very far different as in these countries one person eats as many eggs per annum as 30 or 35 people in India.

This review of the production and consumption of foods of animal origin would show that with increased production their consumption would inevitably also increase and if these products are made available to a section of our people comprising about 50 per cent of the total population, an important step forward would be achieved in solving our food problem, as not only their consumption would ensure better health of the people but would also reduce the demand on cereals which are so much in short supply. The biggest question that poses itself, therefore, is: what stands in the way of increased production of foods of animal origin? This question can be dealt with more fully by examining the present pattern of agricultural operation, the specific problem fields where research work needs to be intensified, certain administrative matters and the pattern of University education in veterinary science as a whole.

THE PATTERN OF OUR AGRICULTURE AND ITS INHERENT DANGER

The present shortage of foodstuffs in the country in spite of the "Grow More Food" campaign organized by the Government brings us to the painful realization that all is not well with the pattern of agriculture advocated in this country. This campaign, although a move in the right direction, suffers from the limitation that it aims principally at production of cereal foods with a view to meet the nutritional requirements of our people. No nutritional pundits can subscribe to this view ; rather, it may have to be admitted that no country in the world has achieved self-sufficiency in food, both quantitative and qualitative, through cereals alone. Integrated agriculture aiming at production of foods of animal origin, therefore, has much to commend and our land resources have to be apportioned for growing food crops and raising livestock. Under the present conditions when more emphasis is laid on the production of plant foods, such as cereals, pulses and edible oilseeds, the chances for the production of foods of animal origin are very little as out of a total of 400 million acres of arable land, the share that goes under fodder cultivation is only about 12 million acres.

The present pattern of utilization of arable acerage without due appreciation of the needs of animals which must also depend upon the produce of the land may not lead to a healthy growth of our agriculture. Some people often make the criticism and others have to bear it that animal husbandry in the country has not made the desired progress as the productive capacity of our livestock is much lower than that of certain advanced western countries. There is no doubt that very much more has to be done in the field of animal husbandry, but as the animals have to be kept on the land, I would rather point out that it is really the land husbandry which must need be improved to cater for the relative food requirements of both humans and animals. The present pattern of land utilization has, therefore, to be reorientated simultaneously with the execution of the various plans of development in the field of animal husbandry so that the potential wealth of our livestock may be fully exploited for the development of our country's economy.

Although such items of food as milk, meat, eggs and *ghee* originate directly from animals, in the production of plant foods also, cattle in India hold the most strategic position as, for their production, animal labour is the most potent adjunct. In the ultimate analysis, therefore, it is the efficiency of animals that determines the country's capacity for food production.

PLAN TARGETS OF FOODS OF ANIMAL ORIGIN

"The object of the animal husbandry plan programmes is to increase the supply of milk, meat and eggs, a greater consumption of which is very essential to balance the present customary diets and to provide efficient bullock-power for agricultural operations in every part of the country".

Milk—It has been reckoned that the total milk output in this country at the beginning of her first five year plan was over 18 million tons which provides only 5 ounces *per capita* consumption. Thus, an appreciable increase in the supply of milk is an absolute necessity. To lay down a national target of milk production to be achieved within the span of the plan periods has not been found possible at this stage of development. As it is mainly through the key village schemes and the national extension and community development projects that the programme for cattle development is pursued by the State Governments, only local and regional targets representing about 10 per cent increase in the total output of milk can be achieved. When the cattle development work has once been initiated in a few selected regions in each State, the intensive and sustained development that would follow with the opening of more such regional centres is likely to result in an achievement of about 30 to 40 per cent increase in the milk output over a period of 10 to 12 years.

The essential corner stone for building up productive capacity of our milch stock is the dissemination of the superior genes from approved and pedigree bulls. Their number during the pre-plan period was insignificant and even now it is not so large, but by the end of the second plan period the programme is intended to produce 22,000 improved bulls, and in the final analysis of the execution of the plan, 950,000 improved bullocks and a million improved cows would also be made available. The operational areas of these achievements would be the numerous key village centres of which 1,258 would be established during the second plan period, in addition to 245 artificial insemination and 254 extension centres to be set up during the plan period. With the expansion of the increasing use of the artificial method of insemination, the country would soon attain self-sufficiency in the matter of high quality stud bulls. The attainments of these targets would provide a strong launching ground for achieving still higher targets of production in these fields.

The most important pre-requisite to taking up an intensive cattle development work is the creation of the necessary incentives amongst the cattle breeders. One of these should be the assurance of prompt monetary return to them through organised co-operative marketing facilities. Needless to say, such facilities would encourage the breeders to grow fodder crops on their fields to feed their stock so that better yields may be obtained from them. The second five year plan lays down a target of organising co-operative marketing facilities in 20 selected key village blocks on a pilot basis. But, if widely extended, these facilities would create the much-needed private initiative and enterprise in the field of animal production which alone can bring in the lasting results. These facilities, if I may add, hold the key to cattle development on the one hand and more production of milk on the other.

Other forms of grants and subsidies to some traditional cattle breeders or to private institutions where cattle breeding and milk production form a part of their function have been provided, but due to lack of full facilities, scientific knowledge and proper guidance, these undertakings have not shown much progress. Such private institutions are the Goshala and Pinjrapoles. Of these numbering 1,100 in the whole country, 346 are to be provided financial and technical assistance during the second plan period so as to place their working on scientific lines and to convert them ultimately into profitable cattle breeding-cum-milk production units. The plan also provides for the grant of subsidies to private individual breeders for the rearing of 35,000 suitable male and female calves so as to use them on maturity for future breeding work.

Meat—Either due to religious sentiments or aversion towards flesh, meat eating at present is not popular amongst the Hindus. Nevertheless, with the growth of population, particularly in the urban areas, meat production has, during recent years, increased enormously for internal consumption. To ensure production of meat under hygienic conditions, which at present are almost lacking in the slaughter houses under most of the municipalities, certain State Governments from their own resources are providing funds to some selected slaughter houses for their improvement and appointment of suitably trained staff to ensure proper inspection and passing out wholesome meat to consumers.

If today sentiments weigh heavily against meat production, as is often argued, what about the economic backwardness of our people which also to some extent determines the food habits? Needless to say, perhaps, as to how sentiments and the popular customs may shape out during a period of ten years hence, the time is not far when the urge for better nutrition backed by economic forces may override the prevailing sentiments and meat may figure more prominently in the normal dietary of our people. It may be considered expedient, therefore, that during the third plan financial assistance may be provided for the improvement of at least one slaughter house in every large city or town.

At the present stage of planning for food, when the sentimental approach to the problem cannot be ignored, no target for meat production is to be found in the official documents of the first or the second five year plans. However, according to the report of the Nutritional Advisory Committee of the Indian Council of Medical Research the target requirement of meat for optimum health of the 313 million adult units has been estimated at 9·4 million tons annually. Unaided by any organised governmental efforts, the total production of meat from buffaloes and pigs has been estimated at about 97 thousand tons, representing nearly one-hundredth of the total requirement.

At present the export of meat from India is almost non-existant. During the years 1954-55 and 1955-56, this country exported beef and mutton to the value of 2·5 and 2·1 lakhs of rupees, respectively. We may consider beef as a closed chapter in the meat trade of this country, but with her large livestock population of other species of animals, such as buffaloes, sheep, goats and pigs, India can build up a sizeable export trade in meat and meat products with the South-East Asian countries where frozen buffalo meat and piggery products are much in demand.

The only scheme pertaining to meat development as formulated under the second plan is the piggery development scheme which envisages, during the second plan period, the establishment of 2 or 3 regional pig breeding centres-cum-bacon-factories and 10 pig breeding units on a smaller scale where pure-bred boars of superior foreign breed or their crosses would be raised for distribution to about 120 piggery development blocks. Private enterprise has already taken a start in the pork export trade and this much-needed State patronage if continued during the subsequent plan periods would put this new undertaking in food production on a much sounder basis.

Poultry and Eggs—During the first plan period little attention was paid towards development of poultry, but its importance as a source of nutritive food for the nation is now being widely recognised. Not only that, it is only in the poultry field where immense possibilities exist for developing the country's economy and contributing substantially to the nation's requirement of food of high nutritive value. In recognition of this, an All-India Scheme for the development of poultry has been launched at a total estimated cost of rupees 258·8 lakhs for establishing, during the second plan period, five regional farms and 300 poultry development blocks in an equal number of districts all over the country. A target of 2,000 breeding stock fixed for each of the regional farms will result in a turnover of 70 to 80 thousand day-old chicks for distribution to all the States in the region. The areas of operation in the regions and the districts will be the numerous N.E.S. blocks and the Community Development Centres where State Planning Departments would provide facilities for the incubation of eggs and the rearing of day-old chicks for supply to the poultry keepers. The scheme also envisages distribution at concessional rate of about 2 lakhs of five months' old birds to village poultry breeders for whom the necessary training facilities would also be provided to enable them to take up poultry breeding on scientific lines.

It is often remarked that poultry keeping is not a profitable concern. Profitability would depend upon the productive capacity of birds but on this consideration no enterprise in the field of animal production can be looked upon as profitable. In parenthesis, I would like to pose a question : is crop agriculture all by itself profitable? If that were so, chronic food scarcity would not be stalking over the length and breadth of the country.

One basic handicap in the production of foods of animal origin has been, from a very long time, the lack of appreciation on the part of our planners on the agricultural side, of what may be called balanced agriculture, and how it should be introduced amongst our farmers. If all food grains produced from the land, including even the coarse ones, have to be appropriated for the feeding of the hungry masses, and only an infinitesimal amount goes to the lot of our domestic animals, you can well imagine what can be expected from our domestic animals.

Recognising that a balanced approach to production of foods of all kinds is essential in the economy of the farming community, the other point that merits consideration is the recognition of applied researches, particularly in the field of animal production, and here a few illustrations of the value of research in this field may have some stimulating influence on the minds of people concerned with livestock research, administration and planning in this country.

RESEARCH AS A BASIS OF DEVELOPMENT

In countries where livestock and livestock products are yielding a good dividend to the producers, the position that these countries enjoy today has been brought up through the pioneering efforts of research workers over a number of years at some phenomenal costs. A perusal of the history of triumphs of veterinary research in these countries would be an eye-opener to most of our people on whose shoulders lies the task of developing our own livestock wealth.

Some Triumphs of Veterinary Research

Early European settlers in South Africa, before the Boer War, were finding agriculture and livestock farming a difficult undertaking. Heavy mortalities used to occur amongst the livestock grazing on the veldts which carried abundant pasturage. Lameness followed by recumbency and extreme emaciation were the prominent symptoms of this malady amongst cattle. This mysterious disease presented a great problem as the then known factors of disease causation, such as the microorganisms (bacteria, viruses or the protozoa) could not be incriminated as the cause of this disease in spite of the meticulous adoption of approved laboratory methods. Another important point observed in the course of field investigation of this disease was the tendency on the part of the grazing stock to devour the decaying animal carcases strewn over the grazing areas. Bacteriological examination of these decaying carcases revealed the presence of an anaerobe, *Clostridium botulinum*, capable of producing a very potent toxin which has been proved to be lethal, on ingestion, to any class of animals or even man. This is just only half the story of this mysterious disease, as it has only explained the cause of deaths of the animals but did not explain the occurrence of the train of symptoms such as emaciation, infertility and the depraved appetite. It remained a zig-saw puzzle for some time till a systematic survey of the soil and the grasses of the veldts, on chemical analysis, revealed a serious shortage of phosphorus, one of the most important elements in cattle nutrition. These informations when put together would present the picture in full as follows: The poor content of phosphorus in the soil gave a poor yield of this mineral in the herbage and cattle grazing upon this poor pasture suffered from phosphorus deprivation, resulting in infertility, bone fractures, poor mik yield and depraved appetite. Phosphorus hunger urged the grazing stock to go after the bones and flesh of the dead animals which provided rich sources of phosphorus and simultaneously also a highly potent toxin.

On the basis of these results, large scale use of phosphatic fertilizers on the veldts or the supplementary feeding of bone meal or other phosphorus bearing compounds to cattle brought about a miraculous improvement in health and the productive capacity of animals grazing the same veldts. These results, so to say, ushered a new era of hope and prosperity to farmers and stock owners and a country where the settlers had to struggle hard for a living is now the proud exporter of the world's most profitable livestock which include sheep and cattle mostly.

The Australian continent, today the abode of the world's best Merino sheep, was less than half a century ago a place where arable agriculture yielded little dividend to the farmers and the grazing area being mostly overgrown with bushes offered little by way of livestock farming. How this change was brought about is in itself a history of the exploits of veterinary research spread over a number of years. As this country offered some vast pasturage in the hinterland and the coastal tracts, livestock farming was the only pursuit to be followed by the early emigrants without much investment. The quality of grazing and the soil conditions placed a heavy premium on the sheep raising enterprise as the average wool production was low and being coarse, ash-coloured and brittle it had poor market value, the adult stock appeared anaemic and undersized and lambs born were prone to go down with ataxia, a demyelinating disease. No organised governmental efforts but private funds contributed by sheep breeders and the wool traders were mobilised to solve the problem of the brittle wool. A large scale field experimentation and laboratory studies financed entirely from these funds provided some strong indication that the deficiency of copper in the herbage was one of the factors responsible for these troubles. Supplementation of feed and the dressing of pastures with copper salts raised the breeding efficiency of and the production of fine quality wool from Australian sheep. As a result of these researches, copper deficiency areas have been mapped out in various parts of the world where sheep breeding is the major stock farming operation. Intensive studies on the role of copper in ruminant metabolism carried out during the past few years have revealed how important this trace element is in enzymic reaction of the living body.

Scouring, fading of the normal colour coat and even infertility are some of the syndromes attributable to copper deficiency in cattle, I may, by way of digression, inform my audience that we have done almost nothing so far in the domain of trace element studies and how their deficiencies are not allowing full expression to the productive capacity of our animals. If Australia is a prosperous country today it is on account of the pioneering work of her veterinary scientists assisted by the funds placed at their disposal.

Veterinary research in this country also has made some notable contributions to nation's agriculture and food supply. Epizootics of rinderpest in cattle, buffaloes, sheep and goats which formerly used to sweep over the country and take a toll of about 2 lakhs of animals annually are gradually being brought under control by the use of goat tissue vaccine developed for the first time in this country at the Indian Veterinary Research Institute. An eradication programme now initiated in every State with the financial assistance from the Indian Council of Agricultural Research has made it possible to keep rinderpest out of the country. Similarly, a very reliable vaccine against Ranikhet disease of poultry, also developed at this Institute, is being widely used in our country and abroad for the control of this disease. Given an effective vaccine, the other main essentials are an effective organization and the necessary funds to lead an all-India campaign for the preservation of our poultry—the only other important source of protein food next to milk.

Our Research Organisation—Existing and Proposed

If application of research can pay such a heavy dividend to the farming community in the field of animal production, any plan for the production of such foods must lay a great emphasis on research so as to build up the proper personnel in specific fields, strengthen the existing laboratories and establish new ones where found necessary. In agricultural sector in general, but particularly in the field of animal production, only very meagre efforts are afoot towards the realisation of this project. This may probably be due to the present indecision as to whether the core of the plan is agriculture or the heavy industries, and which of these two is to receive the highest priority. In the field of agriculture which term today in this country connotes only food crop husbandry, a number of research institutes and commodity research stations have been established. On the animal husbandry side there are two institutions of an all-India character, one the Indian Veterinary Research Institute, Izatnagar/Mukteswar, and the other, the National Dairy Research Institute, Karnal. Besides, three regional Animal Nutrition Centres have recently been organised under the auspices of the Indian Council of Agricultural Research at Anand in Bombay, Haringhatta in West Bengal and Bangalore in Mysore. Both the central institutions in their organisational pattern consist of research divisions adequately staffed to handle problems in their specific fields. In the States also investigations into problem fields at isolated places where convenience and facilities have been provided have been taken up. Thus, each State in the Union has, with the financial assistance of the Indian Council of Agricultural Research in the initial stage, organised a disease investigation unit consisting of two or three components. Each, with a nucleus staff composed of the officer-in-charge and his laboratory assistant, has its own little laboratory isolated from the other as each has to deal with disease problems of some particular species of animals. Then again each State has undertaken one or more research schemes supported by the Indian Council of Agricultural Research or financed entirely by the State resources which also function as independent units. Administrative control and technical supervision of all these separate and individual research units are the responsibilities of the State Director of Animal Husbbandry and Veterinary Services.

If our animals under the present conditions of feeding, management and veterinary aid are capable of contributing to the tune of rupees 5,000 crores annually—a very large percentage of our total national income—their productivity can undoubtedly be increased enormously if research projects are taken up on a more ambitious scale with increased physical facilities and personnel trained in specific problems.

In the field of veterinary research little work is being done outside the central institutes. Experience has shown that in a vast country like India with varying geo-climatic conditions, there is a need for organising research on animal husbandry at all the three levels i.e. Central, State and Regional. While central institutes will undertake problems of larger interests demanding special technical skill and equipment readily available there, the Regional Research Stations would be entrusted with problems of regional importance and required to refer to central institutes such problems as may necessitate the application of special skill and technical acumen. These Regional Research Stations may be financed wholly by the Government of India and allowed to function as sub-stations of the Indian Veterinary Research Institute which would also in the interest of efficiency act as the supervising authority and co-ordinate the results achieved at the Regional Resarch Stations. Each of these must also have a livestock farm attached to it for work on breeding and raising a profitable livestock, conducting feeding experiments with the feeds grown in the region and giving trials to newer drugs and biologics for control and treatment of livestock diseases. Such an arrangement would lead to the desired objective of decentralizing research on regional basis and at the same time ensuring central supervision of a high order.

Every State should have a Livestock Research Station of its own to conduct investigations into problems of local importance, provide a feeder service to the regional and central institutes and undertake application of results of their own researches and those of the central institutes and their regional sub-stations. It is envisaged that a chain of research stations at the various levels and spread over the whole country will offer the only possible means of intensifying research and making available the results of researches for utilization in the field.

SOME PRIORITY PROBLEMS OF RESEARCH

Since the establishment of the Imperial Bacteriological Laboratory (now known as the Indian Veterinary Research Institute) in 1890 at Poona for the control of rinderpest, veterinary research has turned into many directions but rinderpest has continued to occupy the central position of interest till the time when an effective vaccine against this disease had been evolved. The war declared against rinderpest may be said to have been won and its devastating effects on cattle population and ultimately food production which formerly left people helpless would now remain buried as a past history.

Many contagious and killing diseases have also received attention at the Indian Veterinary Research Institute and, as a result, effective biological products developed and manufactured at the Biological Products Division of the Institute have contributed greatly towards the preservation of livestock wealth of the country. With the facilities and resources available at present, various other divisions forming an integral part of the institute are engaged on fundamental researches in animal nutrition, animal genetics and artificial insemination, poultry husbandry and parasitic diseases of livestock. In these fields there are problems of far-reaching importance and vital to the development of the country's livestock which require planning, trained personnel and the necessary funds.

Breeding for Production

Veterinary scientists have "forged" some very important tools and techniques of which the method of artificial insemination is most important. Whereas, in some foreign countries this method has revolutionised cattle breeding for better production, in India, in spite of several centres working at present, a measurable progress according to expectation has not been achieved. Under the animal husbandry conditions obtaining in this country where cattle population is found in small groups in villages far removed from the artificial insemination centres, the progress of this work would continue to suffer from limitations of distance and timely accessibility of semen to the cow, or of the cow to the artificial insemination centre. It would be, therefore, a protafible item of research to devise some means of prolonging the keeping quality of semen, may be, to carry out experiments on methods of deep-freezing semen under our conditions and evolve some effective semen shippers to preserve semen during transit.

It may, perhaps, be rightly presumed that all the bulls that are today employed for the artificial insemination work in the country do not possess a high pedigree, but at the same time it may not be denied that, although in small numbers, such bulls would be available in every State. If researches on the items indicated above bear a fruitful result, each State would be able to establish a few semen banks where deep-frozen semen could be stored for a year or two. This may facilitate a large scale use of good quality semen for breeding more productive livestock.

Progeny testing of stud bulls is another item of work on which no attention has hitherto been given. A bull with a good pedigree is a highly desirable basic material for developing a breed, but more important for a breeder is to know whether a particular bull whose semen it is proposed to use is capable of transmitting the milk yielding characters inherited by him from his dam. This project is long overdue in view of the cattle development work having been taken up on a key village scheme basis for the last ten years all over the country. To say the least, the progeny tested bulls hold the key to the development of cattle in any country and financing research on this project may be looked upon as a sound investment.

Cattle breeding policy today is grading up the non-descript low-yielding stock with some well-defined milk breeds and developing the milk breeds by selective breeding in their home tracts. In certain very large tracts draft cattle predominate, milk production is very meagre and the problem that forces itself is what can be done for increasing milk production in these areas. Cross-breeding between some well-known draft cattle and the milch breeds appears to be the only feasible solution. No practical steps have been taken in this direction as cross-breeding between the known breeds of our cattle is a taboo with our official experts who would not like to violate the sanctity of the pure breed even if it were for putting more milk in our cow's udder.

Feeds and Fodders—a Great Bottleneck

Feeds and fodders present a three-dimensional bottleneck which the agrostologist, the nutritionist and the practical feeders have to get together to resolve. But the position as one may find it today is that the agrostologist is too much imbued with the idea of pastures, the nutritionist advocates the doctrine of a balanced ration—all these in a country where land resources are being utilised for growing cereals and balanced diets are unthinkable even for man—and the practical feeder stands aghast before such jargons.

Our planning for feeds and fodders should more rationally be based upon the needs of the individual cattle owners who do not generally maintain a large herd like the livestock farmers in the western countries and on the system of agricultural practices followed by our mixed farmers. With the onset of several irrigation projects, intensive agriculture with sound rotational system may catch up the mind of our agriculturist and in its wake the idea of pasturage may not be allowed to take root. What is, therefore, likely to follow is crop husbandry in all its phases where cultivated fodder also may find its rightful place. Cattle are maintained under stall conditions of feeding on bye-products of agriculture and the cultivated fodders. Increased yield of food crops and oilseeds through improved varieties of seeds, application of manures, irrigation and protection from pests and diseases will inevitably lead to increase in their bye-products, but all the same, research is indicated on the study of indigenous and some exotic grasses, their ecology, yield and nutritive value.

There is a growing awareness amongst the farmers of the importance of legume crops both as fodder and fertilizer and how many of them, either indigenous or exotic, could be adopted by the farmers both in *kharif* and *rabi* cultivation to provide useful fodder for cattle is the problem for the agronomist to tackle. Likewise, our fertilizer experts also have a problem to tackle and that is to look to some other directions for fertlizers than to appropriate all oil cakes, molasses, blood, bone and fish meals which in all reasonableness should go to our cows for milk production. If synthetic rice or other such foods originating from the Food Technological Laboratory could be available in increasing quantities and rendered more palatable, some coarse grains which at present support our people can more reasonably be diverted to feed our cows in milk. To those who are engaged in the laboratory study of grasses, such as the study of their chemical composition and the nutritive value, it may be pointed out that there is a vast array of indigenous grasses whose potentiality as fodder has not been fully investigated.

Preparation of silage and silage feeding of milch cattle has revolutionised the dairy industry in many countries. What type of grasses can be ensilaged is not really a question, but how best the surplus monsoon-fed grasses could be processed to the maximum advantage of the farmer is indeed a question to which our research workers would have to supply an answer.

Diseases and Pests

Till such time as our farmers, on account of their economic backwardness, do not demand the application of prophylactic measures against the various livestock diseases on payment, the responsibility of protecting our cattle wealth devolves on the State organisations established for the purpose. Our veterinary scientists have made some very notable contributions in the field of animal epizootics with the result that many acute and killing diseases can now be controlled by the use of suitable biological products developed at the Indian Veterinary Research Institute. Nevertheless, the position that may have to be admitted is that there are still certain diseases of our livestock which undermine production and cause serious losses to livestock owners. In this context I refer to foot-and-mouth disease which although causing a low rate of mortality has a very damaging effect on milk production and working capacity of our animals. The situation arising from the ravages of some highly infectious and contagious dsieases of livestock in India has not been appreciated to the extent so as to initiate disease-wise survey of the resultant monetary loss and mobilize all possible resources for suppressing them. In the absence of any reliable information of this nature with regard to foot-and-mouth disease and also in view of the fact that only a small percentage of our cattle population may escape infection, the monetary loss accruing from this disease alone may be considered as enormous.

It is the experience of all workers on foot-and-mouth disease that an animal once recovered from infection is likely to contract the disease again within a few days or months after recovery from a previous infection. In the face of such recurrent threats from foot-and-mouth disease, cattle development may be considered as well nigh impossible. This position can only be remedied if research on foot-and-mouth disease is intensified with enlarged facilities so as to evolve some suitable biological products which could be produced in large quantities at a cheaper cost and afford protection for a longer duration.

Specific abortions where micro-organisms are involved and several hitherto undetermined factors leading to reproductive failure in cattle pose a problem of far-reaching importance, but at the same time, both fruitful and challenging to veterinary scientists. Brucellosis or contagious abortion caused by *Brucella abortus* (Bang) is a disease of world-wide prevalence and almost a nightmare to milk producers even in this country. No organised farms where pedigree stock breeding for the purpose of supplying bulls for grading up the village stock is being undertaken is free from this disease. In view of the fact that an aborted cow remains a carrier of the disease and a very potent source of infection and a bull apparently healthy discharges the organism of the disease in semen, the danger from this disease to cattle breeding and milk production enterprise may really be considered as very grave. The methods of control as followed in other countries, which include slaughter or segregation of infected animals and vaccination of calves, may not be applicable in this country. Several countries have experienced difficulties with the use of the strain 19 vaccine in adult cattle. Its use, therefore, in calves and the adult stock must await critical experimentation before adoption in this country. The other aspect of the problem of Brucellosis that needs investigation in this country, in view of the self-limiting character of the disease, is the significance of the ceased reactors and the possibility that it may offer for devising control measures.

Parasites and Parasitic Diseases

Some chronic and insidious diseases caused by parasites whose number runs into a legion put a very heavy premium on animal production. The poor health of our stock in certain regions highly conducive for the propagation and survival of the parasites may be attributed to a very large extent to the depridations of their various forms and species. To what extent the loss in the animal wealth of any country is account-able to parasitic infestations and diseases may be realised from the statement of Lord John Boyd Orr, an ex-Director General of the Food and Agricultural Organization of the United Nations, that if it was possible to control Fascioliasis (Liver-fluke disease) alone amongst the ruminants of a particular country, the resultant increase in the stock of meat and milk products would suffice to feed the population for a number of years. That may be an eye-opener to any one—scientists, planners or administrators—concerned in food production drives of the country. What is needed, therefore, is the building up of an organization to deal effectively with these marauders, and what more, a stockpile of knowledge on the strategy of attacks launched by them.

Even if it is necessary to fortify the "frontiers of our territory" the livestock, by feeding them better so as to nullify the attack made by the parasites, in a warfare of this nature it would always prove advantageous to infiltrate a little deeper into the enemy lines to study their habits, haunts and habitats and ascertain some vulnerable points for attacking them. Studies on life-histories, bionomics, and ecology of the parasites would, therefore, be of an inestimable value in devising measures of control against them. Intermediate hosts the "fifth-columnists" on which several species of parasites lean for support during the period of their helplessness should also receive attention in our campaign. In spite of the necessary precautions to ward off attack by the various parasites they have their own subtle manners to establish a foothold in our animals. Phenothiozene was once thought to be an "atom bomb" against most of the parasites, but in spite of its killing effect it has proved injurious to the host in most instances. Newer and safer anthelmintic "missilies" for the host but more destructive to the parasites would, therefore, have to be forged in the laboratories—a task which our trained parasitologists may have to be charged with.

The priority problems on which research work needs to be intensified have been indicated together with the benefits that are likely to accrue from pursuing them. No nation can afford to remain unmindful of the technological development being pressed into service in all spheres of human activity. The present gap between the highly- and the less-developed countries can be bridged only if means are provided for the fruitful utilization of the technical knowledge available.

CONCLUSION

Production of food is of vital importance to the nation. The problem needs to be tackled from all angles and the status of livestock, which forms the basis of agriculture in this country, needs to be strengthened. The present lop-sided attitude of agricultural policy needs overhauling to make possible the achievement of plan targets in the field of animal husbandry.

The vast value of livestock and their products can readily be increased ten-fold with the aid of scientific research and given the required technological aid to agriculture as a whole, it may not be altogether impossible to defy the present rate of growth in human population.

The oft-repeated pessimism that Indian cattle are low-producers needs to be modified in view of the very obvious reason that hitherto no serious efforts were made either to develop them or their productive capacity. Such pessimisms, to my mind, are often dictated by impatience from those who want the result in improvement of livestock within the same span of time as often obtained in the field of agricultural commodities. Livestock improvement is a long-range programme as the time between two generations is obviously long.

Livestock development plan visualises a three-pronged attack on breeding, feeding and disease control, all to be pursued simultaneously, if sustained results have to be obtained.

Livestock production is an enterprise of a highly specialised nature demanding services of experts in many related fields. Not only that, our people in every walk of life, be they simple village folk or the industrial magnates, would have to realize the importance of the role our livestock play in building up our country's economy.

SECTION OF AGRICULTURAL SCIENCES

President :—DR. B. K. KAR, M.Sc., Ph.D., F.B.S., F.N.A.Sc.

PRESIDENTIAL ADDRESS

PHYSIOLOGY OF THE GOLDEN FIBRE—ITS NATURE AND PRODUCTION

At the very outset please allow me to express my grateful thanks for electing me to preside over the Agricultural Sciences Section of the 46th Session of Indian Science Congress held in this great city of Delhi. Many distinguished workers in the field of Agriculture have occupied this position before me and this time your choice has fallen on a Plant Physiologist who has been interested in this aspect of plant science and its application in crop production for over a quarter of a century. It is a great privilege to have been offered this opportunity to address on an aspect of plant science which has developed fast and still developing with unabated speed and whose importance is being gradually felt in understanding various problems of plant life and function.

The art of growing plants is as old as humanity itself but has undergone changes through different ages from that of stone implements to the present one of tractors. Rapid progress has been made possible in recent years due to researches made in fundamental conception of Biological Sciences as a result of contribution from allied disciplines like Physics and Chemistry. The vital processes governing a living organism are still predominantly shrouded in mystery, but recent scientific advances have made it possible to look at the problem in a rational way. Recent advances on the conception of Biochemical nature of gene function, the cytoplasmic inclusions and their importance in extrachromosomal inheritance, the idea of mutation, the inheritance of metabolic patterns and the increasing role of environmental factors have given biological research a new basis for interpretation of facts.

The utility of Agricultural research is apt to be judged in terms of its impact on increased production of food or cash crop, but it must be realized that the end product of an agricultural project is dependent upon the interaction of many factors of both scientific and organisational nature ; and so in such project scientists of various disciplines as well as administrators have definite roles to play.

A Plant Physiologist seeks to understand the vital processes which occur in a plant, and always feels the necessity for the synthesis of knowledge gained from studies in other different branches of science. He can not fail to recognise the importance of all techniques and knowledge which other branches provide and thereby help him in understanding plant life as a whole. He, therefore, develops increasing interest in all Biochemical or Biophysical methods of approach to the problem. In a programme of Plant Physiological research, a growth experiment where the rate of growth is measured by simple estimation of fresh or dry weights or a phasic development experiment which is judged by initiation of flower buds, are as important as a critical biochemical experiment on hormone or enzyme reaction, because they all throw light on the behaviour of a living organism.

Agricultural research itself involves the study of behaviour of different plant materials under varied conditions of environment and cultural practices, and so problems on Agriculture should be considered from the above view point. In fact the growing interest in chromosomal studies, the increasing efforts of inducing artificial mutants and application of tracer techniques in the study of plant metabolism, the use of various kinds of synthetic hormones in growth, flower formation and fruit setting, and the useful role of some hormones as specific herbicides, have resulted in a new orientation of agricultural research. New techniques and methods are increasingly finding application in this process. The numerous problems confronting an agricultural research worker, should be tackled in a composite way, so that both fundamental as well as applied aspects are properly integrated for the common benefit. We can forego one, only at the risk of the other. In the present agricultural research set up of the country, this balanced development is somewhat lacking. This may often be due to judging the utility of an agricultural research project on the dictum 'end justifies the means', but, for a research worker, the "means" should be so fundamentally investigated and standardised that the end may safely be predicted and the factor of chance may be reduced to the minimum, ensuring return to the utmost limit.

In the development of agriculture of today the contributions made from the physiological aspects of plant research have acted as valuable aids to crop production and also bid fair to be increasingly helpful in future. It is against this background that my endeavour here will be to trace certain basic physiological processes in the important bast fibre crop of jute (*Corchorus sp*) which is popularly known as the golden fibre of commerce and which occupies a top position in the list of foreign exchange earning commodities, and around which a big industry has been flourishing.

In 1947, after partition of the country, jute industry in India had to face a serious shortage of raw jute stock. Only 16·58 lakh bales at that time marked the total crop output in the Indian Union, while industry demanded about 60 lakh bales. But with foresight, intensive drive and help of scientific research, the position has now been significantly improved. In 1956-57 the production was 42·88 lakh bales. The rate of production of raw jute is still continuing its upward progress and 55·40 lakh bales have been fixed as target of annual production at the end of the Second Plan period.*

In the following pages certain aspects of physiological investigations carried out in the Jute Agricultural Research Institute of the Indian Central Jute Committee have been discussed. The results have brought into light the characteristic nature of the crop and have been instrumental in better understanding of the various problems with reference to crop growth, improvement in cultivation as well as yield and quality of fibre.

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* According to all India final estimate, the production of jute during 1958-59 is 51·78 lakh bales.

Distribution :

Many wild species of jute (*Corchorus*) are found widely distributed in the different parts of America, Africa, India, Burma, Pakistan, China, Japan, Formosa, Phillipines, Siam and Australia (Kundu, 1951), but only two species *Corchorus capsularis* and *Corchorus olitorius* are cultivated for jute fibre crop in the Eastern States of India viz. West Bengal, Assam, Orissa, Bihar and the Terai regions of Uttar Pradesh. Outside India, Eastern Pakistan possesses the most heavily cultivated jute areas and this fibre is also cultivated to some extent in China, Formosa, Burma, Phillipines, Brazil and U.S.S.R. Both the species are of course widely grown. These two species may again be grouped into different regions of cultivation according to the available environmental conditions like nature of soil, prevailing humidity, incidence and duration of rainfall, temperature condition and available sunshine or day-length. *Capsularis* varieties are suited best to the lowland conditions. These can even withstand flood. But *olitorius* varieties successfully grow well under highland conditions. (Kundu, 1956, Dutt 1958).

Nature of Vegetative Growth :

Studies in the growth and development of root-system *in situ,* have indicated the differential nature of adaptability of the two species in different types of soil and under different environmental conditions (Kar and De Sarkar, 1956). In hard clay soil, the tap-root in most cases was found bifurcated after a certain degree of growth in length. In sandy loam soil, the tap-root penetrated deep down to 25·5″ to 32·0″ in the case of *olitorius* varieties and 20·0″ to 22·4″ in the case of the *capsularis.* Further *Capsularis* varieties showed the growth of large number of secondary roots covered with thick growth of fibrous roots giving an appearance of bushy growth. This complex root system exhibited lateral spreading covering a wide area of the soil and penetration to within 6″ to 8″ of soil depth for its fixation and absorptive function. In *olitorius* on the other hand the tap-root attained a greater length and the secondary roots though prominently developed yet were fewer in number with less developed fibrous outgrowths. The root system unlike that of the *capsularis,* tended to grow towards the deeper level of the soil. The two species, thus showed their root-systems to be adapted differently with reference to growth, mode of spread and function in relation to soil conditions. These facts naturally influence their lodging habit as well as absorption of nutrition (Kar & De Sarkar 1956).

It is of importance to jute, unlike the case of the other cereal crops that there should be vigour of vegetative growth with restricted branching because the fibre is laid in the stem during this period. The nature of vegetative growth and factors influencing the rate of growth, therefore, are very important fields of study. Fibre is laid in the stem by virtue of two processes of growth namely by the activity of the apical meristem which is also responsible for the growth in length of the stem and the activity of the cambium which begins its operation just below the apical region. It is this cambium which in course of its activity lays successive rings of fibre cells transversely in the stem (Kundu 1944). This transverse growth is also instrumental in increasing the diameter of the stem. So growth in height and increase in basal diameter are two important features in jute stem development and the performance of a plant may, therefore, be judged in relation to them. Physiological growth data have shown that the nature of growth in height and basal diameter is different in the two species, including their varieties. The relation in the rate of growth in height with that of its corresponding increase in the thickness of the stem during the life cycle of the plant is very important because fibre production depends upon the resultant of these two processes of growth. Though the major part of the fibre (75-80%) is produced by the activity of the successive rings of cambium cells, yet the activity of the apical meristem apparently seems to control the overall growth of the plant. The vegetative performance of a variety as a whole is, therefore, dependent upon the activity of both the apical meristem and the cambium layers (Kar & De Sarkar 1952, 1954).

Such growth may easily be recorded by simple measurements of increase in the length of the stem along with the corresponding increase in the diameter. These two sets of observation have been found to be correlated with the yield of fibre. But an insight into the nature and mechanism of such growth can only be acquired if the different components which constitute the total growth are known. The different growth components may be distinguished as variations in fresh weight, dry weight, bark weight, wood weight and fibre weight. The constituents of the fibre-complex may further be differentiated into phloem-pyramids, fibre bundles, cambial layerings and fibre cells. All the above components manifest themselves in definite proportions during the dynamic process of the growth of the plant. The life cycle of a plant is constituted of different stages or phases of growth when different components are expected to be formed predominantly in different proportions by the inherent nature of the species or variety. It is, therefore, not only interesting but also essential to study the growth of plants, and especially of the jute plant, from the above aspects, in order to collect data on the behaviour of the different growth components, which determine the yield of fibre.

The detailed results obtained on the variations of growth in height and basal diameter of the stem in the two species of *capsularis* and *olitorius* showed specific differences. Tracing the growth in height in four varities, D154, Fanduk (*capsularis*) and JRO 632 and C.G. (*olitorius*), under the same environmental conditions and sowing date, the *capsularis* varieties showed higher rate of growth upto the age of 35 to 40 days than did the *olitorius* varieties. But after this age, the *olitorius* varieties gradually showed increased rate of growth, and with the advancing age of the plant the rate of growth in height became much more accelerated. As a result a marked difference was noticed between *olitorius* and *capsularis* varieties in as much as an excess of 4 to 5 ft. in height, of *olitorius* varieties occurred over those of *capsularis* varieties in 136 days of growth (Sengupta 1954, Kar & De Sarkar 1954, Kar 1954). This characteristic rate of growth in height of the two species was also associated with a transverse growth leading towards an increase in the thickness of the stem by the simultaneous activity of the cambia (Kundu 1944). The rate of transverse growth in *capsularis* varieties was quicker than that in *olitorius* varieties, with the result that during the same period of growth, stems of higher basal diameter were obtained in *capsularis* varieties than in the *olitorius*. The phenomenon of growth in respect to both height and basal diameter, therefore, showed characteristic differential behaviour in the two species. In *olitorius* sp. quicker rate of growth in height gave plants of taller lengths but with smaller base diameters as compared to *capsularis* sp. where comparatively slow rate of growth in height was accompanied by quicker rate of cambial growth giving less taller plants with greater base diameters. These growth features were later on seen to have influenced the production of different growth components which ultimately determine the yield of fibre (Kar & De Sarkar 1957, Ann. Reps. JARI, 1952-57).

The differences in the rate of growth in height also showed themselves up under varietal levels also. Amongst *olitorius* var, quick growth in the early stages over a period of 30-40 days followed by comparatively slower growth over the rest of the growing time was recorded, while in some of the varieties slow initial rate of growth was found to be accelerated markedly in the later stages of growth. The improved varieties of *olitorius* (JRO 620, JRO 632, JRO 753) giving higher yield generally fall into the category of latter type of growth (Annual Rep. JARI., 1954). The most desired type, of course, would be a variety with quick uniform growth throughout. In *capsularis* varieties too, marked differences in growth rate in height were noticed in D154 and Jap Red, the latter showing an increased rate of growth in height but poor yield in relation to D154 of which the rate of growth is comparatively slower, and which does not attain as great a height. This growth aspect has been elaborated later on the basis of constituents of the fibre-complex itself (Kar 1958).

Variations in Growth Components :

Manifestation of growth in terms of height and basal diameter has been further worked out by detailed quantitative estimation of production of green and of dry matter in the stem at different phases of plant-growth, as well as in different regions or height of the plant. The addition of dry matter is the best indication of the growth of the plant, and in jute we are concerned with the variation of dry matter in the plant stem, and its distribution in the bark and the wood portions. The variation in weight showed that the amount of dry material in the basal regions was always more than in the apical portions. The addition of dry material towards the apical region gradually increased with the growth of the main stem in height. In any particular region or level of the stem, the dry material increased with the advance of the growing season. So the maximum dry material was found in the basal region of the stem and this gradually diminished along the stem towards the apical region. The above sequence of changes was found both in *capsularis* and *olitorius* varieties with specific quantitative differences at different stages, for example dry weight in the basal regions of *capsularis* was greater than in that of *olitorius*. Such fact indicates more growth by the activity of the cambium layers in the basal region of the *capsularis* than in the corresponding region of the *olitorius*. But from the percentage distribution of dry weight along the stem, it was noticed that more dry matter was added in the upper regions of the *olitorius* varieties during the process of growth, than in the corresponding regions of the *capsularis*. To sum up, the total dry matter produced is more evenly distributed along the stem of the *olitorius* than along the stem of the *capsularis*, showing the importance of growth in height of the *olitorius* and the significance of growth in basal diameter of the *capsularis* varieties. The total yield is dependent upon height and base diameter in both the cases, but the same is attained by the differential relation of growth in respect of height and basal diameter (Kar & De Sarkar 1957 Annl. Rep. JARI., 1955).

This is proved further by the fact that in *olitorius* (C.G.) the percentage rate of growth in height was found to be higher than in *capsularis,* though the other factors like total dry material and bark formation showed higher values in the vegetative stage in *capsularis* (D154). After 53 days' growth, D154 recorded 130·7% and C.G. 137·0% increase in height, but the total dry material formed after 51 days growth was recorded at 2·436 gms. in case of D154, while C.G. showed an output of 1·686 gms. for the same length of the stem. Similar observations were recorded also in the case of the other components like bark and wood, showing an inherent difference in nature of growth of different components in these two species. The percentage rate of increase in height may be more in *olitorius* but the formation of components like bark and wood, which were also formed as a result of secondary growth in the stem, was found to be more in *capsularis.*

The two important components of the total dry matter of the stem are bark and wood ; of these the former is very important for jute as the fibre is contained in the bark. From the point of view of our studies, their comparative growth relations during the different stages of the plant are essential. A correlated growth in wood and bark takes place and one cannot be increased at the expense of the other, but their variations at different stages of growth have been found to be different in the two species. The growth and development of bark are among the most important features of the jute plant because they have a direct effect on fibre development.

The sequence of changes leading to the differentiation of bark (containing the fibre) and of wood has been studied by tracing their growth during the life cycle of the plant from the very early stage to the mature pod stage. For this purpose the samplings were done weekly, or after each fortnight. Each stem was then divided into successive segments of six inches in length serially numbering them from the bottom towards the apex. Later the values for dry bark as well as for wood were obtained in the case of each such segment. The sequence of changes showed a definite tendency in both *capsularis* and *olitorius,* as for instance, the amount of bark was found to be greater in the bottom regions, and it gradually decreased towards the apex. This tendency was maintained throughout the growing season. Thus at any stage of growth, the bottom portions of the stem always contained more amount of bark than the subsequently formed upper regions of the stem. But the rate of formation in the two species was found to be different in the different phases of growth. The quantity of bark, therefore, varied from the vegetative to the pod stage. In the bottom regions of the vegetative stage, the dry weight of the bark was found to be higher in *capsularis* than in *olitorius.* In the later stages, however, the *olitorius* varieties showed higher values in subsequently formed zones at higher levels on the stem.

A clear picture of the dynamics of quantitative formation of bark was obtained when the analysis was made on the percentage basis of the total dry weight. The percentage of bark weight was found to be maximum in the early vegetative stage, when compared with the total dry weight at that stage in both the species. This maximum value decreased in the later stages, thus showing that materials, other than bark were formed and the rate of their formation increased progressively during the season, of course varying in the two species. *Capsularis* maintained a higher percentage of bark formation per dry weight than did the *olitorius* where there was formation of more dry material in the form of wood. This finding has been corroborated by values obtained on ratio of bark to wood. Further interesting results were obtained by studying the percentage distribution of bark along the length of the stem as compared to the total dry material produced. An important difference in distribution of bark was that the *capsularis* varieties showed higher bark content in the bottom regions than the *olitorius* which showed higher content in the middle and the top regions. This fact again confirmed the nature of growth of the components in relation to length and basal diameter of the two species, as noted before.

Bark and Wood Ratio :

The quantitative growth and development of wood showed similar variations to what was found in the case of the bark values i.e. maximum development in the lower regions of the stem with gradual decrease up along the stem towards the apex. The sequence of changes from the vegetative to the pod stage was traced, and a correlated growth was found to occur between the wood and the bark showing a definite ratio at definite stages of growth and at different levels of the stem. This ratio represented the comparative values of bark as per unit value of wood growth (bark/wood). In *capsularis* the values of this ratio were greater than unity from the vegetative to the flowering stage, thus indicating that more quantity of bark by weight was formed than of the wood. In pod stage, this value decreased. But in *olitorius* except in the early vegetative stage the values were less than unity thereby showing occurrence of early increase in wood formation. This increase in wood weight might also be at least in part, due to chemical incrustation on the cell walls. The results however, clearly indicate the sequence of changes in bark layout in relation to wood growth during the season and also at different heights of the main stem in the two species. (Kundu & Kar 1954).

Fibre Growth and Importance of Fibre Percentage as a Criterion for Selection :

Bark contains the fibre, and the economic value of the performance of a plant is to be judged by the amount of fibre produced, as this fibre is the commercial purpose of jute cultivation. It has been seen previously that fibre production is the outcome of the vegetative growth activity of the plant, which is generally measured in terms of increase in height or basal diameter, but the correct appraisal of growth, however, is dependent on the amount of fresh or dry matter produced, and the quantitative contributions made towards that growth by the different factors or growth components as enumerated above. The most important component is the fibre production itself and its quantitative relation with other components. Detailed results have been obtained on the production and distribution of fibre along the stem, and the relationship of fibre production with other growth components to find out the variations in fibre percentage which is an important quantitative factor to be taken into consideration. Its importance has been shown by Crane & Acuna (1945) & Ergle *et al* (1945) in Kenaf. As fibre production is the result of correlated growth of the various components, the quantitative variation in fibre content naturally shows a similar trend to that of bark formation as discussed above of course with specific and varietal differences.

It is seen that fibre laying begins at an early stage and in plants of 50 days growth an appreciable amount of total fibre, 0·74 gms in D154 (*capsularis*) and 0·66 gms in C.G. (*olitorius*) by dry weight, was found in 30 inches lengths of stem. The estimation of fibre in the apical region of the growing stem at different growth-phases, showed at a distance of 6" from the tip of the stem, very small quantity of fibre formation as a result of initial meristematic functioning there being no differential activity in the two species. During the whole period of growth, the fibre weight in the apical region showed very narrow range of variation, (Kar & De Sarkar 1957) inspite of the fact that plants have passed through different growth phases of the early vegetative stage, bud stage, flowering stage and pod stage. A little increase in the fibre content was found in the bud and flowering stages but it clearly indicated that initial fibre production in apical region remained all along of the same order in both the species and was insignificant when compared with the later formation of fibre in the same region after growth in the length of the stem had occurred to a certain extent and cambium activity had set in. It was, therefore, seen that the specific difference in the rate of fibre growth in particular zones of stem became only perceptible in the later stages of growth due to the activity of cambium layers. In general, the trend of fibre formation was found to be similar in both the species i.e. more fibre formed in the bottom regions than in the upper regions of the stem. In other words the intensity of fibre growth increased from apical regions towards the basal regions of the stem where many layers of fibre-cells were formed. Within this general trend of fibre-growth, the rate of fibre production differed in the two species.

A greater percentage of fibre was concentrated in the bottom and middle regions of *capsularis* relative to the *olitorius*, showing a greater rate of cambial activity in these regions of the stem of *capsularis*. This was further reflected in the percentage distribution of fibre along the stem, where the top region of *capsularis* always showed less percentage of fibre than what *olitorius* did. In *olitorius* the distribution of fibre was more even along the stem. This tended towards the development of cylindrical form of stem in *olitorius*, while in *capsularis* the stem was more tapering towards the apical region. This characteristic difference was due to the nature of vegetative development in—the two kinds of growth, longitudinal and transverse. The relative extent of this pair finally determined the pattern of growth. This physiological difference in the resultant growth pattern is significant because in the two directions of growth, one was compensated by the other. Greater base diameter with shorter stem lengths was attained in *capsularis* as compared with taller stem with shorter base diameter in the case of *olitorius*.

The percentage distribution of fibre in the top, middle and bottom of the stem varied appreciably in the two species, showing the characteristic nature of growth process leading to fibre-production. These physiological growth details have brought into prominence the importance of fibre percentage in assaying the performance of different economic varieties, and in taking into consideration the fibre percentage as a criterion for selection in addition to basal diameter and height of the plant. In jute, it is not possible to obtain fibre and seeds from the same plant, because the whole plant is to be removed from the field to be retted for fibre extraction at bud to flowering stage. For seed purposes, the plants have to be maintained in the field until they are fully ripe. In this stage it is not possible to extract fibre from the already dried up stems and to get a suitable figure depicting true yield and quality (Kar & De Sarkar 1955). To overcome this difficulty, a simple method was evolved known as "stripped bark method of estimating fibre yield". In this method a cylindrical shaped tin foil having a slit on it of dimension 6·0" in length and 1·0 cm in breadth, was used. This slitted foil was pressed conveniently on the stem, and incision made with a sharp scalpel on the bark along the slit. The bark-area covered by the slit was then scooped out. The area and the position of the cut bark portion on the stem were always kept constant. The stripped bark was dried and weighed. The plant was allowed to remain in the field for further growth and seed production. If needed, a second strip of bark could also be obtained at another height to get extra data from the same plant. The correlation studies of these three variable components (a) stripped bark weight, (b) height and (c) basal diameter from the same plant have shown the importance of bark weight as a third criterion for selection in addition to basal diameter and height (Kar 1957).

The fibre percentage varied from early vegetative to the pod stage, showing maximum values during the bud to flower stage, after which the percentage showed no or little increase. In general the percentage values increased from 3·5% to 7·5% in terms of green weight while the corresponding increase in total green weight was of much higher order. A huge amount of green matter required to be produced to have a small fraction of increase in fibre percentage. So a comparative study of the variations of fibre percentage in the different varieties provides very significant data. Indeed, the smaller the range of difference between fibre values and green weight, the more desirable will be the variety from high fibre yielding point of view. Theoretically, one may proceed on this basis, but the high positive correlation values of different growth components indicate a complicated growth system wherein one component cannot be increased at the expense of the other. Hence there is no doubt that the physiological studies which bring into prominence the salient features of the dynamic equilibrium between the different components, have an important role to play in understanding the inherent nature of the experimental material.

Constituents of Fibre Complex:

The fibre layout consists of certain unit structures which are distinguished as phloem-pyramids, fibre bundles, fibre layerings and ultimate fibre cells (Kundu 1942, '43). They are formed in definite proportions at various stages of fibre development, and showed significant variations in their growth and mode of alignment to form the fibre complex. Interesting results have been obtained on the behaviour of these internal variants, which reflect the differences in certain morphological characters such as branching and non-branching habits in the *capsularis* varieties D154 and Jap Red respectively (Kar & De Sarkar 1958, Ann. Rep. J.A.R.I. 1956). It was found that the rate of growth in height and basal diameter was recorded higher in Jap Red than in D154, but Jap Red was found to be a lower yielder than D154. The corresponding estimation of internal variants showed greater amount of growth in (a) number of phloem pyramid formation, (b) fibre bundles and (c) average number of layers of fibre bundles per pyramid in the case of D154 than in Jap Red where the constituent structures were developed less in number, although Jap Red attained greater height and basal diameter. It was significant to note that the number of phloem-pyramids, which was the main layout of the fibre complex was always found to be less in Jap Red, which may be an associated character of its non-branching habit (Kundu & Rao 1954) and may also be responsible for depressing the yield of fibre values. The same trend of variations was also obtained in *olitorius* JRO 632, an improved high yielding variety compared with another *olitorius* variety, *Chinsurah Green.* JRO 632 showed a rapid rate of formation of the internal unit structures even at the later stages of growth than did *Chinsura Green.* The complicated behaviour of internal variants requires careful study for it was evident that they played a decisive role in fibre production.

Stalk and Foliage Relation :

Another important character associated with increase in height and basal diameter of the stalk is the relation of foliage growth. Branching and non-Branching habit is an important character even from commercial point of view. The pattern of foliage growth depend to a certain extent on this habit. No data were available to base a relationship between the degree of foliage and that of fibre production in the stem. The foliage habit together with the potentiality of branching differed in the two species. In *capsularis* (D154) the leaves were smaller, but numerous, and the average period of retention was of 31 days. The growth index of the leaves (L/B=2·05) in both the cases was the same. The percentage distribution of leaf weight and the corresponding stalk weight have been calculated at different phases of growth to bring out their relationship. In the early vegetative stage (45 days), in *capsularis* D154, the proportions of stem and leaf weights were 71·5% and 28·5%. The former increased to about 74·5% and the latter decreased to 25·5% after 66 days growth. The leaf weight gradually decreased to 16·4% at still later stage. While in *olitorius* (C.G.), almost the same sequence of growth of stalk in relation to the output of leaves was obtained in the early stages, in the later stage, leaves accounted for only 11% of the total weight. The above results showed that there was greater leaf-fall in *olitorius* variety than in *capsularis* variety. How far the specific differences in growth relations of stalk and foilage, the pattern of development of leaves and their period of retention and metabolic activity have influenced the fibre formation has not yet been clearly understood (Kar 1955).

The Nature of Flowering Stage :

The period of vegetative growth and the variations of associated growth components as discussed above, were greatly influenced by the passing over to the reproductive phase. The initiation of flowering stage indicated the beginning of gradual cessation of vegetative activity which in jute meant lower fibre production. This aspect of physiological study on the sequence of growth and development was to be considered important in all the crop plants, but particularly so in jute crop, because the harvest time was judged from the flowering habit. The initiation of flowering—phase was found to be influenced by certain environmental factors like temperature and periodicity of day lengths (Kar 1943, Kar and Mazumder, 1954 and Sengupta *et al* 1950, '52). Under normal sowings (middle April to middle June) the early varieties came to flower within a period of 90-100 days and the late varieties in 130-133 days. Both the species could be induced to flower early under artificial short-day conditions and to delayed flowering under long-day conditions (Kar 1943 Sengupta and Sen 1944). The initiation of flowering, therefore, varied according to different sowing dates. Interesting results were obtained on the flowering habits of the two species and their different varieties, and their influence on fibre growth has been analysed.

The *capsularis* varieties, after initiation of first flowering, showed a gradual rise in the rate of flower formation reaching a maximum of flowering followed by a gradual decline. The active flowering period and the range of flowering, therefore, were confined to a range of about four weeks with maximum flush occurring in the second week of flowering, thus showing more or less a curve of normal nature. But *olitorius* varieties on the other hand showed, from the first initiation of flowering a slow and prolonged flowering the period extending over about 8-10 weeks with periodic flushes. Thus the curve is one of a rhythmic nature (Kar & Mazumdar 1954, Ann. Rep. JARI., 1954, 1957). In *olitorius* varieties no period of optimum flowering could, therefore, be clearly demarcated as in case of *capsularis*. The nature of difference in flowering behaviour was reflected in the relative growth of the vegetative phase. The occurrence of the well defined quick flowering phase demarcated *capsularis* varieties into phases of active vegetative and flowering periods, showing corresponding variations of fibre growth. But in *olitorius* varieties such clear demarcation was not possible as both the phases continued simultaneously for a long period. In *capsularis* varieties the emergence of optimum flowering period was indicative of its optimum period of performance and then gradual cessation, while in *olitorius* varieties, the emergence of flowering period was not indicative of such a sequence. This physiological characteristic of the relationship of the two phases has a bearing on the judging of the time of maximum performance and expected time of harvest to get higher yield.

From practical point of view, therefore, the status of flowering in the two species has different meanings, and should be taken into consideration in assaying the maturity of a plant population in the field for purpose of harvestings. It will be economical to retain the flowering *olitorius* varieties in the field for a longer period in expectation of more fibre growth and consequent increase in yield. But not so in the case of *capsularis* varieties where the activity was limited within a narrow range.

Physiology of seed formation:

The difference in flowering habit in turn affects the formation of fruits, their ripening period and the seed formation. In the preceeding chapters stress was laid on the various aspects of vegetative growth, but the problem of seed production and that of its preservation are no less important to ensure the initial material for cultivation. For obvious economic reasons, much attention has been given to the different aspects of fibre production ; but not enough data are available on the various aspects of seed production. From the results obtained on the flowering habits of the two species, it was evident that due to a prolonged range of flowering period, the growth and development of capsules in *olitorius* showed wide variations in their maturity and seed setting. These variations were narrowed down to a great degree in *capsularis* due to the narrow range of flowering period and majority of the capsules matured under more or less similar conditions.

The jute seeds were found to have practically no period of dormancy and germinated even inside the fruits on the availability of slight moisture. This characteristic necessitates careful methods of preservation, to maintain the viability of seeds (Ghosh *et al*, 1957). The average number of seed-settings in capsules formed in the different weeks of the flowering period showed a tendency of maximum seed output per capsule in the region of the optimum of the curve of flowering in the case of *capsularis* varieties. But in *olitorius* no such tendency was observed ; but the average maximum seed output per capsule was noted to occur irregularly during the different weeks of the flowering period. The number of seeds per capsule varied from 30·6 to 38·1 in *capsularis* and from 123·1 to 197·0 in case of *olitorius*.

In order to study the performance of seeds formed during the different weeks of the flowering range, the capsules were grouped week-wise according to their points of origin on the flowering curve, and the progeny thus raised were studied with reference to vegetative and flowering habits. The nature of flowering curve showed the same specific characteristics irrespective of their points of origin on the flowering curve. But with reference to vegetative growth in height, some interesting observations were made. Considering the percentage distribution of different height groups in the population, it was found that a large number of taller plants was found in the progeny raised from seeds obtained from capsules which were formed in the late-half of the flowering curve. This was more marked in *capsularis,* but the tendency was also observed in *olitorius*. In further modified experiments with early selfed seeds and late selfed seeds, the same results were obtained with reference to the height groupings. The physiological reasons for this differential behaviour amongst the seeds formed at different regions of the flowering curve are under further investigation. It may be stressed here at this stage that such investigations into the developmental phases of seeds with reference to different factors are likely to lead to some profitable results and in screening high potential seeds for multiplication.

Nutritional aspects :

Nutritional requirement is another aspect of crop production which has received widespread attention from workers of various disciplines. This problem is associated with almost every aspect of crop-growth and its improvement whether it is a breeding programme of evolving new and higher yielding varieties, or agronomical trials of crop management and response to environmental and ecological factors, or from physiological point of view of plant function and behaviour, or biochemical aspect of intricate cell-matabolism. The boundaries of our knowledge in plant nutrition have, therefore, widened rapidly in recent times.

From the stage of our preliminary knowledge, when only eight elements were known to be essential for plant nutrition, we now find that many of the elements of periodic table have some function or other to play in plant metabolism, and are capable of absorption by the plant. From major inorganic and organic fertilizers to trace elements and recently the metal chelates have all by exhibition of their role brought into light the complex nature of the problem, and have moreover advanced our knowledge towards better understanding and utilization of different nutrients.

Agricultural research in every country has pointed out the effect of mineral fertilizers on the maintenance of soil fertility, and increase of the crop-yield. But the knowledge of a complete and balanced fertilizer and the respective response of crops are essential pre-requisites for judicious application of fertilizers. Recent investigations on heavy manuring in the case of cereals (especially paddy) have shown that the effect was dependent on the assimilative activity of the plant, rather than on morphological characters. A very close relationship, for example exists between assimilative activity of nitrogen and the adaptability of plants to heavy manuring. A dynamic equilibrium is maintained for the synthesis of proteins from absorbed nitrogen (ammonium) in rice plant. The ratio between soluble nitrogen and protein nitrogen in the plant is, therefore, of prime importance (Baba 1954). The difference in response to heavy manuring in the case of Indica and Japonica types of paddy varieties has been explained on this basis. The above results on paddy have been quoted in order to draw attention to the importance of the physiological nature of adaptability of the crop itself to the different manuring treatments. This aspect should be studied in all nutritional programmes for investigation. The problem of jute may be different from cereals when the effect of nutritional treatment is examined from the point of view of fibre-production which is the prime activity of the vegetative phase and which in turn is dependent upon so many quantitative factors as have been discussed at length before. Hence analysis of nutritional response in jute plant is still very difficult and complicated. At present certain aspects of approach towards the problem of nutritional requirements in jute have been discussed below.

The nutritional requirement is dependent upon the vigour of growth, and from that point of view jute varieties are to be considered as short-duration crops of about 125-145 days growth, out of which the grand period of active vegetative growth ranges from 30-35 days and continues upto 85-90 days. In case of *capsularis* the sequence is quicker, whereas in the *olitorius* it is more prolonged. To induce growth of roots and vegetative shoots, cultural operations like thinning and weeding are essential. The problem, therefore, resolves itself into firstly, the growth habit of roots and their absorptive capacity, secondly, the adjustment of application of fertilizer by taking into consideration the nature of growth, and thirdly ; the kind of nutrients and their functions in physiological growth processes of the various quantitative factors.

Detailed manurial trials with all possible combinations and under different agro-ecological conditions of jute growing areas were conducted by the Jute Agricultural Research Institute, in order to investigate (a) effect of N, P, K and their different combinations (b) sources of nitrogen (c) time of application (d) variety-cum-spacing-cum manuring (Reports Jute Agri. Res. Inst. 1952-57, Das *et al* 1955, 1957, 1958). Results have been obtained by Chaudhuri (1942, 1946, 1951) from field trials and by Sengupta (1953) from studies in sand culture experiments. The investigations have shown a great response of jute to nitrogen, applied either in amounts of 20 lbs. 40 lbs. or 60 lbs. of N per acre. The effect of change from 20 lb. to 40 lbs. was more marked than of one from 40 to 60 lbs. Ammonium sulphate was found to be the best source of nitrogen. Individually P and K were not effective, but in combination with a certain level of nitrogen, their effect was evident. With 20 lbs. of nitrogen per acre, P & K were not advantageous, but with higher dose of N, they become effective in giving somewhat higher yield, but specific difference was there. In their response to the difference in levels of P & K *capsularis* was found to be more sensitive to the levels of phosphorus and *olitorius* to those of potasium (Sengupta 1953).

Experiments conducted at Jute Agricultural Research Institute and in cultivators fields in jute growing areas of different States have shown that when crop is 1-1½ months old, application of ammonium sulphate as top-dressing at the rate of 100 lbs. per acre (20 lbs. N) gave an extra yield of 2-6 mds. of fibre per acre, both in *capsularis* and *olitorius*. In case of *capsularis* jute, however, if the dosage of ammonium sulphate was increased to 200 lbs. per acre (40 lbs. N), the increase in yield up to about 4-9 mds. of fibre per acre was obtained ; but in *olitorius* it was not found to be economical. Amongst the organic sources of nitrogen, town compost was found to be the best. An application of town compost at the rate of 40-80 mds. per acre at the time of preparatory tillage, followed by 50 to 100 lbs. of ammonium sulphate as top-dressing when the crop was about 1-1½ months old, was found to be the best. The addition of calcium as lime was found beneficial to the normal growth of the plant in acidic soils. Increased fibre yields were obtained by the application of lime at 3-6 mds. per acre either alone, or in combination with nitrogen. (Mukherjee *et al* 1955, Das 1957, Das & Kundu 1957).

The results obtained on pot-culture experiments carried out in Jute Agricultural Research Institute showed that Ammonium nitrogen showed a better effect on the growth rate and on the consequent production of green weights of the plants, thereby increasing the fibre yield when compared with the effect of nitrate nitrogen. But when the percentage of fibre was calculated on the corresponding green weights produced under different ammonical and nitrate nitrogens, a significant increase in fibre percentage values was obtained with sodium nitrate, potassium nitrate and calcium nitrate treatments relative to the yield obtained with treatments of ammonium sulphate, ammonium chloride, ammonium phosphate and ammonium sulphate nitrate. Both *capsularis* and *olitorius* showed similar results.

It was, therefore, observed that nitrogen in whatever form it was made available, was instrumental in stimulating vegetative growth. Out of different sources of nitrogen ammonium nitrogen was found to be more responsive, than nitrate nitrogen so far as the vegetative growth in jute was concerned. But nitrate nitrogen in association with Na, K and Ca was found to be more effective in actual fibre production, as was shown by tha increased values of fibre percentage as against the comparatively lower value of total green weight. This has brought into prominence the role of cations in the physiological changes occuring in the cells leading to the formation of specialized fibre cells. The importance of presence of Ca was more marked than Na or K in both the species. This aspect, with special reference to the metabolism of fibre-cells is under further investigation.

The time of application of nutrients for their best possible utilization by the plant has been worked out from physiological stand point. The growth habit of root-system in the two species has indicated that *capsularis* with its numerous fibrous-roots was better adapted to absorb nutrients quickly and from a greater soil volume than *olitorius* with its deep penetrating and less spreading fibrous root-system. The differential effect on growth after top-dressing of the nutrients has revealed the functional nature of the two root-systems. The change in the nitrogen status of the top-leaves in the two species has further confirmed this.

Nutrients in full single dose and in different split doses given during 30 days, 45 days and 60 days growth, showed maximum growth performance in one single dose and that too when applied during 30 days growth of the plant. The later the application of nutrients, the less the effect on growth. In cases where split doses were applied at short intervals to plants having 30 days and 45 days growth, favourable growth response was obtained. Under field conditions this may not be economical due to the labour and other factors involved.

Recently, application of nutrients by means of foliar spray has given good results in certain crops (Bonton 1954, Thorne 1955, Low 1954). Jute is a crop with heavy foliage growth ; so the above method was also tried. The results obtained were quite favourable, and the chemical estimations of the sprayed leaves showed increase in their nitrogen content after 3 and 6 hrs. of spraying. Urea was found to have been absorbed by the leaves in the shortest time, and corresponding increase in yield of fibre was also recorded. Ammonium sulphate was also quickly absorbed, thereby increasing the leaf-nitrogen content, and the fibre-yield was appreciably increased. Though this method has produced favourable results, yet its economics as compared to common method of application of nutrients to soil has yet to be worked out.

The question of the quality of fibre :

In view of what has been discussed before regarding the nature of growth and the pattern of fibre lay-out during the life cycle of the plant, it is evident that jute fibre is a very heterogenous material from the point of view of age, maturity, size and chemical inclusions. Jute fibre as known to the commerce is constituted of an innumerable number of ultimate fibre cells of varying dimensions in length, breadth and thickness. The commercial fibre constituted of these cells are mutually joined together in a net work fashion. The jute fibre reed, which is the product of a single plant, as obtained after retting and extraction, results during the process of growth into this meshy structure, the degree of meshiness also differs according to the position of the fibre formed on the stem at the base, middle or top. A successful technique for quantitative estimation of "meshiness" has been offered by Sen (1951). It has been pointed out before, that fibres are formed by the activity of the growing meristem of the apex as well as by the activity of the cambium, which forms the main bulk of the fibrous region and are arranged in layers forming pyramidal wedges which taper outwards (Kundu 1954). The above process of fibre formation is dependent upon the nature of growth rate, varietal characteristic and available environmental factors. A fibre element thus formed has its own varied processes of stretching, thickening and impregnation to attain maturity.

It is, therefore, expected that fibre elements of different ages, showing variations in dimension, wall thickness and chemical inclusions would be met in a jute fibre sample. Thickening and lignification of the cell walls of the fibre cells showed differentation at different stages of maturity (Macmillan *et al* 1955). The variations in the lignin content of the fibre at different growth phases of the plant have been worked out in J.A.R.I. It was found that lignification takes place with the age of the fibre and after an optimum value it remained more or less constant. Along the length of the stem at any particular stage of growth the basal fibres are more lignified than the middle and the top fibres are the least lignified. The thickening of the cell wall and the changes in the lumen size also differed according to the growth of the plant, and along the length of the stem as in case of lignification (Rao and Kundu 1955). The stage of lignification of jute cells was determined by Sen (1956) from physical studies.

In view of the above facts, it is not possible to judge the quality of a jute fibre even roughly on the basis of a single criterion as is possible in case of cotton fibre on the basis of halo-length. The heterogenous jute material require more than one test to judge its quality. To a technologist, the capability of a fibre sample to be spun into required fineness of yarn is the standard method of judging the quality. Certain characters of jute from technological point of view, which enable one to judge the quality of fibre have been worked out in great detail by Sen (1954, '55, '57) such as (a) filament length (b) meshiness (c) cross width of the filament (d) filament surface (e) density and gravimetric fineness (f) filament strength (g) moisture relationship (h) elastic properties of filament (i) Yarn standard which is given by the standard of Quality Ratio which is equal to breaking load in lbs divided by grist and multiplied by 100. The fineness of a jute yarn is indicated by the grist which measures the mass in pounds of a length of unit 14,400 yds. (j) faults of yarn which the industry has often got to face are mainly irregularity, slubbiness, hairiness and speckiness. Sen has for the first time succeeded in predicting the grade so far as spinning to a particular type of yarn is concerned, by a physical method from knowledge of fineness, flexural elasticity and intrinsic strength of the single fibre elements of commerce (1957a).

The above characters are developed in the process of growth and as a result of physio-chemical changes occurring in the fibre cells, and one character is more or less dependent upon the other. For instance, if we take the two most important characters (a) elastic properties and (b) lignification as determining the quality of fibre and influencing other characters enumerated above, we find that they are antagonistic to each other. Impregnation with lignin gives support to the cellulose matrix but decreases elasticity and increases rigidity. Actually it has been seen that fibre cells at the top regions of the stem are of better elastic quality than those of bottom regions due to the difference in lignification as mentioned before (Sen 1955). In this connection the work of Freudenberg (1953) and his collaborators are also important. These authors pointed out that activity of lignification is due to the effect of "coniferin" which is produced in the cambial regions of the plant. The majority of jute fibre is produced by cambial activity and how far this relationship of coniferin production or other substance of like nature holds good with the process of lignification in jute fibre is worth investigating. It may be mentioned here that fibre produced from apical meristem are of better quality than secondary fibres produced from cambial activity, which may be explained on the basis of different origin of the two sets of fibres. Sen (1947) showed from physical tests that there is a small proportion of fibre of a distinctly different quality from the major part in a reed, whether this former is derived from meristem activity is yet to be established. The variable and complex nature of fibre, therefore, as aforesaid precludes any estimation of fibre quality on the basis of a single character. Moreover quality is judged after the fibres have undergone a process of retting and extraction (Kundu 1954). It is also known that retting is the most important factor which influences the production of good or bad quality fibre.

In view of the above situation one feels the difficulty in proceeding to elucidate the problem of improvement of quality of the fibre with respect to certain inherent characteristics as we have in case of estimating yield on the basis of base diameter, height and fibre percentage of the plants. But an acquaintance with the knowledge of the nature of growth of the plant and the physio-chemical changes occuring during the process of fibre-formation have tended towards certain conclusions on the basis of which one can proceed to get improved quality of jute fibre. In this respect it is, desirable that varieties selected for cultivation should have characteristics of quick uniform growth and maturity. Fanduk (*capsularis*) variety produces very good quality fibre and is also a quick early maturing type. JRO 632 an improved *olitorius* variety is also a rapid growing one, giving good quality fibre. Attempts should be made to evolve uniformly quick growing, early maturing types, of course not impairing yield, under improved methods of cultivation.

In this direction, significant advancement has been made by introducing hand pushed seed drills for jute cultivation in lines or rows (Sanyal 1952). Comparative experiments have shown that plants grown in lines show uniform rate of growth in height and basal diameter and the growth variations are reduced to very narrow range. Plants grown by broadcast method show wide growth variations producing a population of heterogenous individuals with a wide range of variation in height and basal diameter. It has been seen that thick stems or short plants do not produce good quality fibre. It has also been found possible to reduce heterogeneity and raise a crop of uniform performance when plants are nurtured in well arranged lines with proper adjustments of spacings according to the varieties. Line sowing also helps in easy and cheap cultural operations by using hand wheel hoes. All the plants thereby receive the same cultural treatments which is not possible in broadcast method where plants grow irregularly without proper spacings.

In addition to cultural practices, the time of harvest is an important factor for obtaining quality jute. The longer the plant is allowed to remain in the field the more is the deterioration in the fibre quality. Harvesting at early bud stage has been found to give good quality fibre than in pod or late pod stage. A scientific confirmation of the general agricultural practice regarding harvesting of jute has been offered by Sen (1957).

It will be an interesting and profitable aspect of research to find out the effect of manurial combination like nitrogen, phosphate and potash or of micronutrients on the production of quality fibre. Chemical nature of the fibre in relation to the growth of physical characteristics may lead to a better assessment of fibre quality. Spinning quality in general decreases with increasing nitrogen content and with increasing lignin, fat and wax content (Sarkar, Bandopadhya and Nodder 1944).

As mentioned above the most important single factor in producing quality jute is the process of extraction of fibre by process of retting, which is a very complex bio-chemical process involving many factors and certain organisms (bacteria and fungus) which initiate the reaction. The question of quality in jute fibre, therefore, presents a very complex problem which requires further investigation. It is essential to find out the basis of certain characters which may be utilized and developed further into a criterion for estimating quality in the living population.

Conclusion :

In conclusion it may be said that an attempt has been made in the preceding pages to represent the various aspects of jute fibre production, in such a way as to bring forth the inherent nature of the material one has to deal with. I am aware of limitations one has to face in dealing with Biological problems ; but I have tried to study the subject from physiological point of view, and if I have been able to acquaint you with certain salient features, thereby providing a basis for further research and development of the most important commercial crop, then my purpose is served.

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SECTION OF PHYSIOLOGY

President :—Dr. N. P. Benawri, M.D. (Hons.).

PRESIDENTIAL ADDRESS

"SOME THOUGHTS ON THE TEACHING AND RESEARCH IN PHYSIOLOGY"

Members of the Sectional Committee, Ladies and Gentlemen,

I am grateful to the members of the sectional committee for the honour they have done me by unanimously electing me President, Section of Physiology of the Indian Science Congress Association for this annual session. I am fully conscious of the great responsibility of this position and of my own short-comings. I crave your indulgence and hope that you would not mind the short-comings in my address.

The title of my address is "Some Thoughts on the Teaching and Research in Physiology". The problem however is a vast one and my remarks would naturally be limited to my own little experience of over 18 years as a teacher and investigator in Physiology. My remarks would be further limited to teaching and research in Physiology in Medical Colleges in our country.

Content and Aims of Physiology Teaching to Medical Students.

Physiology teaching to the medical students has to be so organised that it may prepare them for the eventual practice of Medicine. A highly technical approach is neither desirable nor useful. Out of a hundred students perhaps one may be so stimulated by the subject that he may decide to adopt Physiology as a career but the rest are mostly destined to be practitioners of medicine. Under-graduate teaching in the subject has, therefore, to be adapted to the needs of this vast majority of medical students who would ultimately practice different branches of medicine.

This raises certain important issues. Should a physiology teacher exclude from his teaching material, otherwise useful, but of no direct clinical applicability? Should the teaching of physiology to a medical student be purely scientific or purely applied? Opinions on these points are naturally divided. Those in favour of scientific teaching of the subject argue that they are neither teachers in clinical medicine nor is it their duty to teach only those aspects of Physiology which are of direct application in medicine. Those holding the other view, however, claim that scientific knowledge of physiology is not essential for understanding medicine. After all medicine was practiced even before physiology acquired the status of a separate discipline. The utility of physiology for the ultimate understanding of medicine is, however, universally acknowledged. Too applied an approach, however, is likely to confuse the novice since names of most of the diseases would mean little to him until he has seen the cases in the wards or received clinical lectures on the subject. A happy middle course of scientific teaching combined with exposition of the clinical applications of physiological knowledge would perhaps be the best. In this connection mention may be made of correlation clinics during the preclinical course, and of the basic science-clinical conferences in third, fourth and fifth years. These would be discussed later in connection with integration of physiology teaching with other disciplines.

Teaching of Principles and Concepts.

Physiology is an experimental science. Each fact, concept and hypothesis has emerged as a result of years of experimentation. For a truly scientific appraisal of the various 'mechanisms' and 'processes' it is, therefore, necessary that their experimental background be studied in detail. For the research worker such minutiae regarding his problem are all the more important. The teacher of Physiology is thus confronted with a number of problems. Should he merely enumerate and mention the various principles, concepts, hypotheses, mechanisms and processes or would it be better for him to elucidate them with the help of their experimental background? Then again, should he make a selection among them and teach only the so called 'important' or fundamental ones? Also physiological principles are applicable to a wide variety of biological situations and without proper examples of their application the 'principles' would not only lose their significance but are also liable to be misinterpreted by the student. How much time should therefore be spent by the teacher of physiology in exemplifying the principles is another problem in itself. These problems become all the more important in view of the fact that most of our Universities are now adopting the 18 month pre-clinical course, cutting down the teaching period of physiology by six months.

Emphasising broad principles and concepts, simplifying generalisations, and omitting a lot of experimental details has its own value in an introductory course and is, to a large extent, necessary and also unavoidable. Burdening the student with too much of detail or giving too many examples has the drawback of deviating him from basic principles and confusing the issue by making it too complicated. On the other hand when the teaching is confined to a mere mention of the conclusions of a number of years of experimentation and thinking, there is danger of converting the student into a mere automaton devoid of the faculties of critically analysing data, weighing evidence and deriving sensible conclusions from a mass of facts. This again would lead to a very unhappy state of affairs.

The success of a physician to a large extent depends on his ability to observe and elicit symptoms and signs, derive intelligent conclusions from these and correlate it with his theoretical knowledge and arrive at the correct diagnosis. A student who was converted into an 'idiot savant' by teaching based on a mere recital of facts can hardly be expected to think for himself. He would hardly make a good physician. If the aim of medical education is the creation of thinking physicians it is necessary for the teachers in physiology as also in other disciplines to so plan their teaching that it is neither a mere recital of facts nor overburdened with too much detail or too many examples. The student should be taught to observe for himself and question rather than accept a statement. It is thus necessary not only to teach basic concepts but to also elaborate briefly the manner in which they have been arrived at. The importance of historic approach to the subject is therefore undoubted. Some elements of comparative physiology are also useful as they make a student appreciate the evolution of a particular mechanism.

For practical work also the problem that confronts a physiology teacher is, whether to make the student learn certain experimental techniques which he is not likely to use in clinical medicine but which bring out a fundamental physiological principle or to limit the practical work to only such exercises on human subject as the students would also use during clinical examination of patients. According to this view, animal experiments could only be demonstrated. A lot could be said in favour of both view points. In my opinion, some animal experiments of an elementary nature are best performed by students themselves. This would emphasize the experimental nature of the subject. It would also serve another useful purpose. The slightly differing results obtained by different students for the same experiments would make them aware of biological variability and of the utility of satistical analysis in medicine.

Correlation of Physiology Teaching with other Disciplines.

Physiology teaching for a medical student has to be correlated with other related disciplines. This co-relation has to be in two dimensions (1) Horizontal—with Anatomy, Histology, Bio-chemistry and Pharmacology ; (2) Vertical—with Physics, Chemistry and Biology on one hand and with the clinical disciplines on the other hand.

(1) HORIZONTAL CORRELATION

Forty or fifty years back Professors of Physiology used to preside over the teaching of Histology, Bio-chemistry and action of drugs in addition to Physiology. With the advancement in our knowledge of these disciplines, they started separating out. Even now Histology and Bio-Chemistry teaching is under the administrative control of the Physiologist in many medical colleges in India. There is, however, a growing tendency to separate Bio-chemistry as an independent department and to merge Histology with Anatomy. This no doubt helps in the advancement of knowledge but at the same time it complicates the planning of a general course in Physiology.

(a) *Bio-Chemistry.*

There is no doubt that Bio-chemistry as a science is a vast one and a very important one too. One has, therefore, nothing to say against independant department of Bio-chemistry for advanced research in the subject. One cannot, however, fail to remark that Physiological chemistry which is to be taught to a medical student is only a small portion of the Science of Bio-chemistry. Also an undergraduate medical student cannot possibly find time to grasp and imbibe the intricacies of Bio-chemistry. This problem becomes more acute in view of the new 18 month pre-clinical teaching programme which is being accepted by most of the Indian Universities. It is therefore desirable that the teaching of Physiological-Chemistry and also principles of Bio-Physics to the medical students should be under the administrative and academic control of the

Professor of Physiology. This would ensure proper orientation of the subject and its better integration with Physiology.

(b) *Histology*—

Teaching of Histology is in an uncertain state in our country. In some medical colleges, it is taught with Physiology, while in others it has been recently passed over to Anatomy. Whatever be the merits and demerits of this transfer to Anatomy, one thing is definite that in that case it will raise another problem of integration with Physiology. Histological structure of an organ or tissue is usually conditioned by its function. It is, therefore, desirable that Histological structure of tissues and organs be discussed together with their function. If the teaching of Histology be transferred to Anatomy department then its integration with Physiology would have to be carefully arranged to ensure proper understanding of functional Histology. In this I agree with Jessop (1953) that "from the point of view of teaching medical students, Histology is a more fundamental part of Physiology than it is of Anatomy".

In this horizontal correlation, the ideal should be to provide such an integrated picture to the student that he may be able to understand the principles as connected stories and also unnecessary duplication may be avoided. Some people are totally agginst any duplication in teaching. In this connection, however, it is necessary to take a balanced view. While the integration of various disciplines should aim at avoiding unnecessary duplication, it need not altogether discard useful duplication. It is common knowledge that at times duplication is very helpful in understanding a problem thoroughly and forming correct impression about it.

Integration with Anatomy of a fairly high degree has been obtained at Birmingham. I personally feel that it presents certain difficulties. Dissection of the human body is region-wise whereas Physiology is taught systemwise. Except for nervous system and perhaps respiratory system, integration in other systems presents a lot of practical difficulties.

This integration is off-set by certain difficulties which are common to this as also to the vertical correlation. Among these are:—

(1) Limitation of time.
(2) Limited senior staff who can bring about efficient correlation.
(3) Lack of enthusiasm in other departments.
(4) Traditional departmental policies, reservations, doubts and academic inertia. These will be discussed later on after dealing with the problem of vertical correlation.

(2) VERTICAL CORRELATION

Correlation of Physiology with clinical subjects in Medical Colleges in our country is usually far from satisfactory. A few lectures or lecture demonstrations in Applied Physiology are usually held in the later part of the final year of the Medical Curriculum in most Medical Colleges. It hardly serves any purpose. The students at that time are so busy preparing for the final examination that they do not pay much attention to these lectures. Also the importance of the physiological basis of Medicine loses a lot of its appeal when it is unconnected with actual clinical teaching on the same topic. It is suggested that applied Physiology lecture-demonstrations should be spread out over the entire period of three years that a Medical student spends for clinical training. These should also be so arranged that applied aspects of the same problems are being taught as are being discussed by the clinicians in the hospitals. In addition to these applied Physiology lectures most medical colleges in India have a programme of about 10 lecture-demonstrations in clinical medicine to the 2nd year students. In these lecture-demonstrations also there is usually no attempt at correlation with Physiology.

Experiments in this direction which are being tried in foreign countries also need mention in this connection. Correlation clinics in 2nd year classes conducted by senior and experienced staff of the department of Medicine have been found very helpful. Similarly basic-science-clinical-conferences conducted jointly by the departments of basic medical disciplines and the clinical departments during the entire duration of a clinical training of a medical student have also proved useful. These experiments also need extensive trial in our country.

Correlation of Physiology with Physics, Chemistry and Biology has hardly been tried in this country. Physics and Chemistry form—so to say—the backbone of Biological Science and the contribution of zoology to Physiology need hardly be emphasised. In our country Medical Colleges are usually run by various Governments or by private bodies. A few Medical Colleges only are run by Universities. Correlation of Physiology with the basic Sciences of Physics, Chemistry and Biology is, however, only possible for centres where Medical Colleges form a part of the University-campus. Such a plea has been made by Pandit (1958) and I entirely agree with his views on the subject. Such a correlation needs frequent meetings between the Professors of Physiology, Physics, Chemistry and Biology. It further needs sustained efforts on the part of all these four Professors for drawing up such schedules of teaching which may aim at correlation of these disciplines with Physiology.

The difficulties in correlation of Physiology teaching with that in the other disciplines—specially the clinical subjects have already been enumerated. The most important difficulty to my mind is lack of enthusiasm and unwillingness to depart from usual departmental policies of the concerned Heads of Departments. With a little more co-operation of all the teachers concerned, a lot could be achieved in this direction.

Problems relating to students.

One serious problem in this connection is poor knowledge of the language in which students are taught and have to express themselves. Physiology as also other subjects of the Medical curriculum have been taught through the medium of English language in our country. Now since Independence, with increasing emphasis on Hindi and other Indian languages, English is being neglected at the school stage. This has resulted in a very low standard of knowledge of the English language in an average medical student. Teaching of Physiology has suffered a lot in recent years due to this language difficulty. Perhaps such a thing is unavoidable during the transition period through which we are passing these days. The difficulty, however, is there all the same.

Problems relating to Teachers.

To be a good teacher one should possess a thorough knowledge of the subject, ability to express himself well, well-balanced personality and missionary zeal to stimulate the student to improve his learning.

Absence of the temptation of private practice and poor compensation for loss of practice have been great deterrents to brilliant people from taking up Physiology teaching as their career. The result has been a great paucity of really capable teachers in the subject.

Teachers of clinical subjects have, besides, the temptation of private practice, great scope of social advancement, due to professional contacts, etc. Scales of pay in most of the medical colleges in India envisage compensation for loss of practice to a Physiology teacher up to a maximum of about 200 to 250/- per month. This is evidently inadequate compensation in view of the private practice of clinical teachers running usually to several thousand rupees per month.

The only permanent solution of the problem lies in stopping all kinds of private practice in Medical Colleges and providing uniform adequate scales of pay to the teachers of the basic sciences as well as of the clinical subjects. This would have the additional desirable effect of fully harnessing the energies of the clinical teachers for research. Such a plea for increasing the emoluments of Medical teachers has been made repeatedly—e.g. by Bhore Committee, Gregg Committee and Central Health Council, etc. Technical personnel including Physiology teachers should, if anything, be paid more than the administrators. In our country, however, it is the reverse. Salaries of Principals and Professors of Medical Colleges should be at least on par with those of Commissioners and Secretaries to Government and others.

To enlist good teachers, it is also necessary that due recognition be given to teaching ability. Academic promotion should be based on teaching ability. To maintain a continuous supply of trained personnel in Physiology, it is also necessary that bright students with aptitude for teaching and inclination towards this subject be encouraged to take up post-graduate studies in the subject. Rewards or financial support to such persons during their M.D. or Ph.D. programme is likely to yield fruitful results.

Physiological Research :

Physiological research in Medical Colleges in this country has gained impetus since independence. Indian Council of Medical Research is providing more and more funds for physiological research. A lot, however, still remains to be done to further advance this cause. One would wish that there were more collaboration between the basic Sciences and the Clinical departments so that more research on applied problems could be possible. This could be further aided by the provision of some research beds in medical college hospitals where the physiologists and teachers of other basic disciplines could admit subjects suitable for the problems in hand. The treatment of the subjects, however, should remain in the hands of the concerned clinicians.

More powers regarding disposal of research funds need being given to heads of research departments with a view to ensure better returns in the form of good work. Since a good proportion of research workers in Physiology are teachers in the subject it is natural that improvement in their emoluments and recognition of their good work would go a long way in encouraging research.

Teachers in most medical institutions are rightly encouraged to do research. It has a good effect on the students as well, since they are, so to say, brought up in an environment of research.

It is, however, necessary that a proper balance between teaching and research be kept by each teacher. If brilliant teachers get so engrossed in research that they leave teaching to those who have not been so successful in teaching then the effect on the students would not be a healthy one.

It is neither possible nor my intention to enumerate all the research problems in Physiology and allied disciplines being tackled in our country. A lot of excellent work is being done in different laboratories.

I will only make a passing reference to some research activities of this laboratory, in connection with Digestive system and nutrition.

Some studies on gastric function :—

A feeling was growing in one's mind that alcohol or oatmeal gruel was not a very suitable stimulant to the gastric mucosa in Indian subjects. A more suitable test meal was found in 'Potato meal' and the results of gastric analysis were compared between alcohol meal and Potato meal in 20 healthy subjects and between oatmeal gruel and potato meal in another series of 20 healthy subjects (Benawri 1946). The response to potatomeal was found to be better than the other two meals. It is suggested that where biological response to stimuli are studied the stimulus should be so selected that it is not foreign to the tissue in question otherwise abberrant reactions may be observed.

Some studies on nutritional and allied problems.

In the past one generally tried to correlate a single nutritional deficiency to a particular clinical condition met with in mal-nutrition. Taking Phrynoderma as an example one finds that Nicholls and Nimalsuriya (1939), Lowinthal and Pallister (quoted by Bicknell and Prescott) associated it with a deficiency of Vitamin A. Aykroyd and Rajagopal (1936) failed to find such an association. Gopalan (1947) attributed Phrynoderma to a multiple deficiency of essential fatty acids and vitamins of the B group together with vitamin A deficiency to a lesser extent. Menon, Tulpule and Patwardhan (1950) failed to confirm Gopalan's finding. They also found skimmed milk to be beneficial in this condition. Benawri and R. B. Mathur (1953) in a study of 1127 subjects observed 36 cases of Phrynoderma and concluded that multiple deficiency of Vit. A, vitamins of the B group, essential fatty acids and perhaps also low protein intake are its causative factors. The tendency now is to consider most of the nutritional disorder Syndromes as due to multiple deficiencies rather than to a specific deficiency.

Amylolytic activity of the Saliva of new-born infants.

Klump and Neale (1930) reported paucity of amylase in duodenal contents of new born infants and during the first 12 months of extra-uterine life. In view of this finding Salivary amylase assumes greater importance in the infant than in the adult. Keens and Hewer (1929) found Ptylin absent in the Saliva of 7 out of 12 foeti between 17 weeks and full term. It was, therefore, considered useful to study this problem further. Benawri and B. B. L. Mathur (1955a) reported that in a series of 200 infants (including 12 premature ones) an amylolytic enzyme was present in all the cases. They, however, found (Benawri and B. B. L. Mathur 1955b) that the activity of this amylolytic enzyme in the Saliva of new-born infants was 1/35th to 1/40th of that in the adults.

Calculogenic effects of wheat as compared to rice.

McCarrison (1931) in experimental studies on rats found wheat to be more calculogenic than rice.

Wilson and Mukherji (1935) observed greatly increased urinary output on rice diet as compared to wheat diet in a human subject.

Patwardhan (1952) has drawn attention to higher incidence of urinary Calculi in wheat growing areas as compared to regions where rice is the cereal in the diet.

Benawri and Sharma (1957a) in a series of 14 human subjects reported that the total urinary output per 24 hours is much higher on rice diet than on wheat diet. They (Benawri and Sharma 1957b) also reported that the concentration of Calcium, Phosphate and Oxalate in the 24 hours urine is much less on rice than on wheat diet. These observations lend support to the contention of McCarrison and offer an explanation to the finding of Patwardhan. Further work on this problem is in progress.

CONCLUSION

In this brief address I have attempted to place before you some problems of teaching and research in Physiology in medical colleges in our country. I have also given certain suggestions for improvement in these spheres of activity. Only joint effort on the part of all teachers and research workers in Physiology can bear fruit. It is earnestly hoped that such efforts shall not be wanting. I would not take much of your time and would now conclude by thanking you all for the patient hearing that you have given me.

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SECTION OF PSYCHOLOGY AND EDUCATIONAL SCIENCES

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PRESIDENTIAL ADDRESS

"SOME ASPECTS OF PSYCHOLOGICAL THEORY AND APPLICATION IN INDIA"

CONTENTS

I. A review of psychological theory.
II. The situation in India : (*a*) The ancient tradition.
III. (*b*) The contemporary picture.
IV. Psychological application : (*a*) Assessment of general mental ability.
V. (*b*) Experimental studies at the Banaras Hindu University.
VI. The need for research publications.

I

A REVIEW OF PSYCHOLOGICAL THEORY

1. It will be readily agreed that *science* can be understood in two ways. It may be defined as a systematised body of facts ; or again it may be described as a systematic enquiry into particular phenomena. In short, it is a body of *knowledge,* as well as a definite *technique,* an attitude or a point of view. It is generally assumed that any science is merely the specific expression of an urge for curiosity. It may be an idle theoretical curiosity to probe a little deeper and to explore a somewhat wider field. But this urge is often dictated by some practical necessity, that not merely spurs us towards advancement of knowledge, but also determines the field for improved skills. During a war, there is a considerable pressure for the development of weapons for offence and defence, as well as for ancillary crafts and skills. But during the prospects of peace, there is a relatively freer field for the evolution of commerce, and agriculture, of arts and industry.

2. *Philosophy* and *magic* are the remote ancestors of scientific enquiry. The former symbolises the aspect of theoretical wonder and the latter represents the need for effectiveness in practice. I believe that "*philosophy* began with the effort to understand and explain the twin mysteries of *life* and *death.* While one phase of this endeavour is noticed in theology, the other is to be found in the ontologies and cosmologies that are systematised in philosophic literature."[1] But there was a parallel group of thinkers that found better satisfaction in puzzling over the span of activity lying between the two mysterious termini of the *before* and the *after* ! A great deal of attention was paid by them to the actions and interactions of living beings among themselves, as well as to their

relations with and reactions to the physical environment. Animistic concepts were the most popular at one time. However the phenomena of *life* are highly complicated with strange changes during germination, growth, maturation, preservation and evolution of the species, as also in the individual's disease, decay, senility, death and extinction. There are also the alluring aspects of 'conscious control', and the implications of adjustment by animals and plants to the wide variations encountered in their environment: There are "the antagonistic responses of 'affection for' and 'aversion to' other objects and situations ; the search for food, shelter and security ; the urge for improvement that is reflected in the selection of better modes of living and mating, etc."[2] All of these indicate the functioning of *a central organ that can carry a little of its past and determine its present in the pattern of some more or less dimly anticipated future.* The human being has the privilege of consciously experiencing these aspects of activity as memory, imagination and thinking. He also enjoys the surges of emotions and feelings, as well as the onrush of hopes and fears that define the field for his efforts, and also form the common fabric of all his aspirations and anxieties. He has also the facility for communication with other fellow-beings and the prospects of a group life.

3. The terms soul, *psyché* and ātman gave an identity as well as a distinction to such experiences. But the explanatory virtue of these concepts faltered before the problems posed by psycho-physical interaction. The visual perception of a face is undoubtedly related through intimate physiological visuo-cortical processes with the pattern of the electro-magnetic light waves reflected from the visible object ; but the perception is qualitatively a unique fact, free from the 'limitations of time and space' that form the essential framework for the objective stimulus (situation). *How* the physical processes are transmuted into the psychic and the psychic are transformed into the physical? These querries have opened an arena for speculative polemics. But the content is often confused with the mass of epistemological implications of quasi-logical slogans from different schools ; and we find ourselves drifting towards a morass of unresolved metaphysical standpoints. So the more *practical* psychologists tend to turn away from this unpromising land of 'no return', and they calmly add another *myth* for the curious. They refrain from using the 'emotionally loaded' terms of the soul or psyché, and restrict themselves to the use of the more familiar term *mind.*[*] But the safety thus gained is only nominal. The moment you knock at the 'why' and 'what' of *mental processes,* you get faint echoes of the psyché like the sighs of a restless skeleton in some obscure cupboard. Now the practical enthusiast sheds the *mind* also ; and he tries to make good the loss by emphasizing *behaviour* and stressing the little known neurological, endocrinological and other covert aspects of bodily behaviour. While bewailing the limitations for research developments in modern times due to narrowminded and misplaced humanitarianism, he turns with a gusto to the study of rat-behaviour, etc. These lower animals offer a free field for experimental variation. And once they can prove the indications of memory, thinking, etc. in the behaviour of the rat in the laboratory, then they are inclined to consider similar possibilities in man. However, these gentlemen often hesitate to accept the possibility of a mind or of mental processes, and take delight in positing some secret and unknown 'intervening variables'.[3] I see in this the flickering of a positive urge to

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[*] It is interesting to recall here a line by Kabir: Tā mana kauṁ khojahu re bhāi, tana chūṭe mana kahāṅ samāi. (Trivedi, G.—*Padma-pāṇipa,* 1955, p. 4).

facts, and this may indicate a turning point in their negative virtue of looking at 'non-mental behaviour' only.

4. Other psychologists feel that conscious phenomena alone constitute the essence of this field. They also restrain incursions into metaphysics. While inclined to accept the basic assumption of some form of psycho-physical interaction, they are prudent enough to adopt the expediency of psycho-physical parallelism (Wundt, Titchener, etc.). But the laboratory technique seems primarily a field for behaviouristic methodology. A study of behaviour is in fact the most common method for estimating the experiences and attitudes of others.[*] Hence we often notice among experimental psychologists an uneasy alliance between an admission of conscious experiences amenable to introspection, as well as the attempt at a point-by-point correspondence with bodily behaviour and the environmental situation. Thus one may say that, the offshoot of *behaviourism* is indeed a necessary development from one aspect of experimental psychology. But the admission of conscious experiences also opens the romantic vistas of feelings and emotions, of ideas and imagination, of needs and wishes and the impact of successes and failures. The piecemeal studies of early *structuralists* with their jolting references to illknown neurological and physiological phenomena could not satisfy the multifaceted variety or limit the scintillating brilliance of the human conscious experience. So we come upon two major reactions: On the *one hand,* we find the development of an emphasis upon unprejudiced observations and näive experiences, and we lay stress upon a fuller appreciation of the *whole* or the total psycho-physiologico-physical *gestalten.* Thus many under-valued aspects come to find a place in the psychologist's description of behaviour. On the *other hand,* the studies of deviant human behaviour by medical men have revealed potentialities of conscious hopes and frustrations in the moulding of one's social character and somatic symptoms.

5. The discoveries of Freud and others about the role of unknown and unconscious processes in shaping an individual's conscious appreciation of the present as well as the needs and demands for the future, have opened a fertile field for observation and systematic speculation. At the same time, there is an increased scope for quack adventurers and antisocial psychopathic deviates by the addition of an unlimited field for exploiting individual ignorance. I think this is largely due to the ambiguous usage of the term 'unconscious'. For one, it refers to mental processes that are merely *not-conscious ;* and for another it refers to the specific portion of repressed desires, wishes and needs that are also unknown and not-conscious. A good deal of this confusion could be easily reduced by using the qualitative and descriptive term ***nonconscious*** in the general sense, and by restricting the term ***unconscious*** to indicate the specific functional or constitutive background of the given processes.[4] The practical universality, protean variety and extraordinary potency of the hidden unconscious processes, easily induces some thinkers in India to more or less identify the jīvātama (or soul) with the nonconscious organisations of the hypothetical *Id* and the *Superego.* It seems to me that there is a wishful confusion of the explanatory concepts of Freudian metapsychology with a metaphysical functioning ***real being.*** In this field again we come across attempts to draw a closer parallel with bodily pro-

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[*] It is interesting to note that when Arjuna wants to know about the *sthitadhī,* he asks "how does he speak, sit and walk"? (Kiṁ prabhāṣeta kimāsīta vrajeta kiṁ. *The Bhagwadgītā,* II, 54)

cesses, either of some specific organs (e.g. the genitalia), or of the general visceral or other metabolic changes. I would draw your attention to the similar developments in the early stages of experimental psychology.

6. A closer study of the individual's perception with a particular reference to the bodily processes uncovers a number of complex problems in the transformation of the physico-chemical stimuli into the electrical and chemical processes of the nerve-impulses as well as their coordination and conversion into motor and glandular responses. There are several types of mysterious 'intervening processes'[5] or variables. I have called them mysterious, since in spite of their being technically dependent variables, they do fairly often exhibit a disconcerting degree of independence, amounting to an unaccountable eccentricity. This is noticed on the one hand in the constancies of perception, and on the other hand it is evident in the everyday experiences of common illusions. It may also be noted that each psychological experience is imbedded in, or emerges from a social background. As social experience is the matrix for the regulative *moral* attitudes, no practitioner of applied psychology can plead impunity on the ground that psychology is a positive science. Applied psychology being a practical endeavour, it falls essentially within the orbit of ethical directives. It seems in short that there are a considerable variety of deeper problems, which we have to face for a complete understanding of our living experiences: the semi-concrete physico-physiological, the rather abstruse psycho-biological and the dominant psycho-social problems. We can transfer them for the time being to the rare 'perfectionist', but we cannot afford to wait for the benefit of his maturer wisdom, which is only a promise(?) of the more or less distant future. In the meantime we have to buckle ourselves with such equipment and tools as happen to be available and turn them to the best possible account. Although complete success is a far-off goal, yet some improvement in our present adjustment is our near aim. However we need not ostrich-wise deny the different problems now, as they are bound to crop up at a later stage. This means that we have to hasten slowly forwards, feeling our ground with cautious footsteps. But the gain of each new step would increase our confidence in discovering a safe footing for the next. While we need not blindly proclaim that this is the *only* way to progress, we could certainly acclaim that this *also* is helping our journey. We need not be prejudiced towards the different endeavours of others, or exclaim that their faster advance is only in a longer blind alley. Our progress is indeed likely to be more of a spiralling ascent in which we pass through various stages, gaining from each earlier stand-point a different impulse and a richer appreciation of the warp and woof of our living experience. But for long our search will be incomplete. This is the ***divine discontent*** in the lot of the student of psychology, which carries him along the paths of this ever-varying *saṁsāra cakra* (world cycle). Not the promise of plentiful success, but the privilege of an honest effort in the contest for a good cause is our primary motive.

II

THE SITUATION IN INDIA : (a) THE ANCIENT TRADITION

7. The Psychology in India, whose traces are available in our ancient tradition, has been more interested in the *dynamics* of experience

than in anything else. We are familiar with the dictum: *yogaścitta vṛtti nirodha* (Yoga is the discipline of mental dispositions). This is a well-known expression of mental dynamics. But this tradition has been overlaid by two factors: (1) the tendency to ascribe all movement to the 'primum mobile immotum" (e.g. *apāṇi pādou cālayati sarvān*) ; and (2) the literary tendency to revel in the genteel luxury of more or less stable feelings and sentiments (*sthāyibhāva*). The association of specific feelings with sundry ideas and situations in literature did not take long to reach the stage of a static and a petrified ideal.

8. The situation is further complicated by the peculiar Indian tradition that the mind (*manas*) is not-conscious or *jaḍa*. Thus on the one hand it tends to give a higher status of activity to the organs of knowledge and action (jñānendriyas and karmendriyas) making the mental experience merely a dependent variable ; and on the other hand it is hard put to explain the complex processes of comparison and coordination, of thinking, desiring, etc. The function of the soul is limited: It is only to illuminate and endow consciousness to the functions of the *antaḥkaraṇa*, which usually includes *mana, buddhi* and *ahaṁkāra*. There is a diversity of opinion as to which of them is in closer proximity to the source of consciousness. But in each case, the *conscious character is the quality of a complex experience* only ; and there is *no* reference to any elementary *sensations* as basic experiences of cognition. Further, there is no clearcut distinction in traditional Indian Psychology of the commonly accepted three modes of cognition, affection and connation. The experience is assumed to be an *organised whole* that can never be contained in its parts, although it can be analysed into parts: the whole is both immanent as well as transcendent. In practice again there seems to be a reflection from theology upon the Indian tradition: This is the free use of the concept of force or *śakti*, which gives rise to a kind of 'faculty' psychology. We often talk of memory, imagination, etc. as expressing the activity of certain faculties or forces, *e.g.*, smaraṇa śakti, kalpanā śakti, etc. The basic disadvantage of faculty psychology lies in the assumption that mere naming is a sufficient explanation of the given facts. Hence it is rejected on the critical level, although it is commonly accepted at the popular level. Thus the Indian usage is unfortunately open to the accusation of sponsoring a popular and pseudo-scientific system of water-tight faculties. Due to the aforesaid differences any attempt to uncover identities, or identical developments between modern western psychology and ancient Indian thought is often an unprofitable adventure. The *Science of Emotions* is an ample testimony to the paucity of possible simple comparisons. We have to more or less distort the one to fit with the other. For instance the Indian terms of common usage usually indicate an overlap of the modes of consciousness, e.g. *vicāra* and *cintā* are not merely cognitive terms, they also include aspects of conation and affection respectively. I do not consider it either a special defect, or a virtue of the Indian tradition. I recognise these differences. They are largely due to epistemological and metaphysical standpoints, so each view should be appreciated in its own context. An alien 'frame of reference' is often likely to discover illusions than facts. On the whole we may say that there is an equally distributed emphasis upon the conscious as well as the bodily dispositions that carry the impact of an individual's activity or *karma*, and jointly constitute the mould of his current acivity. I have elaborated the concepts of organisation and of psychophysical dispositions elsewhere.[7]

III

(b) THE CONTEMPORARY PICTURE

9. Modern education in India began with a bias for British ways of thinking and feeling. So we followed their lead in the analysis of cognitions and affections, as well as their synthesis through association. Later we gloried in the marvellous systems of instincts suggested by Wm. McDougall. At about this time we also got in touch with European and American views. Many of us were simply overwhelmed by the speculations of Freud, and others! While psychology has been evolving, ploughing fresh fields and opening new prospects for theoretical speculation in Europe and America since the first great war (1914-18) ; we in the Indian universities have found it difficult to keep up with this breathless pace, or cope with the modern flood of American publications. We seem to be divided into two groups: In *one* group are those who uncritically accept the suggestions of the latest publication available, and thus keep abreast of their times. In the *other* group are those who have stopped short at a likely looking point with McDougall or Freud, Koffka or Lewin, etc. Our progress is also hampered otherwise: Our laboratories are uniformly ill-equipped even for demonstration of the large variety of sensory and perceptual phenomena ; our libraries have a long lee-way to make up in filling their shelves with journals reporting research in the various branches of psychology. These jointly handicap our capacities for original research. I may also confess to the existence of an uneconomical attitude among some professors (seniors with philosophic training only) to pose as walking encyclopaedias of psychology, rather than be humble specialists in a small and limited field.

10. In India the wise man has been less tempted by the magical alchemy of the 'philosopher's stone' ; but he has been always hungering for that knowledge "by knowing which there shall remain nothing more here left to be known" (yaj jñātva ne' ha bhuyo 'nyaj jñātavyam avaśiṣyate. *B.G.*, VII, 2). This ancient tradition has also reduced our interest in apparently minor topics of research. We wish to create wonderful world-shaking events ; and while waiting for these fortunate inspirations, we continue to retail information culled from publications in Europe or America. This is the darker side of the picture ; but there is also *a thin silver lining.*

11. The younger workers in most Indian universities have undergone a clearer training in modern psychological theory ; they have also some grasp of the experimental techniques. The paucity of the laboratory equipment however does not give them sufficient scope to exercise their enthusiasm as well as their talents. Possibly it is not very well-known to our *higher* administrative authorities that the field of scientific psychology is indeed very vast, and that the exigencies of adequate experimental control often need all the apparatuses supposed to be peculiar for all sorts of specific fields. We need equipment of physics and electronics, of chemistry and physiology, and the facilities for zoology, a children's nursery and a medical clinic. If we had all these, even then, in order to merely demonstrate typical experiments of our current text-books, we would need a separate workshop as well as an appropriate institutional environment to prepare suitable combinations of these apparatuses and techniques. My statement would look like a very tall order indeed, specially as most of our students (I do not want to add the staff) are ill-equipped, being mostly without a preliminary back-

ground of physical, biological and social sciences, which are basic for an adequate grasp of psychology.

12. The hard realities of our situation thus force us towards extra-laboratory fields for exploration and research. Hence *individual differences* in the fields of clinical and educational psychology have attracted most attention. I do not intend to minimise the interests of the Mysore Laboratories in animal psychology, specially learning with ants and rats, or a Calcutta interest in fishes,[10] or the Assamese study with rats.[11] But you will agree that these are isolated expressions of an individual's occasional interest ; as there has been no sustained study or a systematic programme for research. Physiological psychology has also had a restricted interest.[12, 13] Child psychology is more of an anecdotal character, although there have been interesting observations with a psychoanalytic or a mental assessment angle.[14, 15, 16] The use of experimental control or variation is only a promise of the future. The field of Social psychology has appealed to a few, and the interest in scientific sociometry is fast assuming a place of honour.[17, 18] Many times it appears here that we are more interested in collecting data than in suggesting fresh hypotheses. There is a much larger quantity of work in the field of *measurement of intelligence* (or general mental ability). Here we have the two currents of endeavour from professional educationists and academic psychologists merging together in increasing the 'heap' of observations. It is regrettable however that sustained systematic efforts are more often tales of *promises* that remain unfulfilled.[19] This is a field of psychological application which well illustrates the potentialities as well as the weaknesses of contemporary psychologists in India. So we will consider it in some detail.

IV

PSYCHOLOGICAL APPLICATION : (a) ASSESSMENT OF MENTAL ABILITY

13. We find early attempts by educationists in the field of *individual testing* at Madras, Dacca and Lahore. Binet type tests were tried with much enthusiasm. The work at Madras and at Lahore was able to earn Ph.D. degrees from some American universities. But little or no further work was done for several decades. Later workers in the field at Calcutta, Surat, etc. appear to ignore them by giving a scanty reference, if at all, and neglect their data for comparative remarks. Thus all these studies remain isolated adventures, which have had little or no repercussions on our general academic life. *Group testing* has been reported since long and follows the pattern of using some wellknown tests from England or America in English, or by preparing some Indian language versions. The statistical treatment is however usually very meagre and often non-existent. When in 1934 I enquired from some Indian scholars about their conclusions with special reference to the norms used and the assessment of the significance of the reported differences ; I was rather surprised to discover their negligence of statistical aspects. It may be added that most of these clever people managed to secure departmental advancement. It seems that they soon gave up all interest in psychological testing, as we seldom come across their contributions even years later. The common defect of slipshod statistical details was probably due to, (1) lack of statistical interest ; (2) the primacy of career advancement ; (3) the smug expectation of *real scientific* work being available from Britain or America ; (4) a sub-conscious

belief that India is too backward for the application of scientific psychological techniques.

14. Apart from the above-said work done by official education departmental personnel, there were a few studies in universities, colleges and some missionary schools. These are characterised by a more sincere desire to prepare tools for application to the living problems of school education. Not merely we find a larger number of observations, but also a genuine attempt at discovering *norms* from the given experimental data for the local student population. However most of them usually overlook the work done by others in India. One may suspect that the desire to gain prominence (!) by posing to be the *first,* or the 'one and only' in India, has proved too strong to overcome isolation in their reports. This situation is typical[20] upto the time of the political independence of this sub-continent (with a few rare exceptions).

15. It must be noted that during the last great war (1939-45), a great deal of encouragement was obtained by the workers in this field with the specific emphasis upon psychological testing by the Directorate of Personnel recruitment of the Army in India. But the data was kept in a hush-hush atmosphere. This handicap was somewhat removed by the Employment Selection Bureau of the Home Department, Government of India,[21, 22] in its assessment of war-service candidates for the I.C.S., I.P.S., etc. A considerable stress was also laid upon the development of suitable tests for general usage. It is unfortunate that all those data were lost during the aftermath of partition, closely following upon the heels of a hurried abolition of the said bureau. However the example of the central government had its appeal for certain adventure some industrialists, notably the Tata Iron and Steel C. Ltd., Jamshedpur ; and it also gave an indirect support to enthusiastic educationists in Uttar Pradesh. The industrialists were interested in improving their personnel problems so when the Government of India abolished the E. S. Bureau, it was only a matter of time for their imitators to follow suit. The snag in all these industrial selection procedures is, that while you want efficient and expert personnel, you also want that their individual proximity should be comforting to you. Hence the *employer's* personal preferences are always inclined to overlook the so-called 'minor deficiencies' of the less efficient, or even the 'ill-experienced' applicant for a given job. The practical psychologist cannot overlook that the employer not merely wants a *hand,* but a hand with whom he can work and feel at home,—and therein lie the germs of antagonism to psychology, limited nepotism as well as for unrestricted jobbery and corruption. Some specific weightage is indeed the well-deserved privilege of the employer ; but when this romps unrestricted, then it creates alarm everywhere.

16. Turning to the interests of enthusiastic educationists, we find the first Bureau of Psychology in Uttar Pradesh, established at Allahabad. (By now there are several vocational and educational guidance bureaus in other states). It was mainly meant to prepare suitable psychological tests, and to train adequate personnel for using and interpreting test data for guiding the school population of that province. It has collected data in thousands, but suitable scientific analyses are not keeping pace with its practical large scale commitments. Much is being done, but much more is yet to be done. I believe that in any government department there is a disproportionate emphasis upon quick results. This is even more so in a democracy, where the vociferous politicians are hungering for talking points about 'practical benefits'. Hence there is a pardonable tendency to pass off psychological tests as eminently useful, while

they are relatively untried, or only the hopeful progeny of an inventive brain. Such attempts have brought a depression in the testing trade even in America, and no wonder similar processes may be leading to second thoughts nearer home. We have to undertake elaborate revisions for refinements and validating studies before we should launch on large-scale psychological testing of students in our public schools. The *Minutes of the Workshop on Educational/Vocational Guidance* (1955)[23] shows that validation studies by Bureaus are often absent, and many times inadequate. However this lacuna is not so evident in the reports from the university centres. So I am definitely of the opinion that the research projects of the provincial bureaus should be arranged in cooperation with the local universities, and teachers' training or education departments, and that some of the more academic aspects parcelled out to these academic bodies. This will mean, (1) the training of a larger personnel ; (2) an adequate scientific treatment and detailed scrutiny of the test data ; (3) an independent source of information for the refinement and the revision of the given tests ; and (4) a very considerable extension of the area of scientific psychological testing. I am convinced that the possibility of a complication of administrative responsibility and of carping criticism could be largely reduced by emphasising the academic intention of refining the revisions of the given tests. Let us not forget that all government experts are either ex-university teachers or students ; so they may be expected to rise above their shallow suspicions and prejudices, when our scrutiny is only to suggest improvements of the next edition. Again, there is a considerable amount of psychological test data being collected by the defence services. They destroy their *dead* data from time to time. It would be very useful, if some could be handed over for post-mortem studies by the university research students. Some years ago I was informed that the *dead* data had been already 'sequeezed out of all research value' prior to its destruction. With due respects to the chief of the research wing, I remained unconvinced. I do not think it either prudent or profitable to maintain the facade appropriate only to an alien bureaucracy. A change, even one graduated and cautions is a necessary corollary of the changed times. So I would repeat with my learned friend and predecessor in this chair at Madras, that "for an adequate development of research . . . it will be necessary for the psychologists serving in the Psychological Research Wing to hold conferences with psychologists working in the universities and work on certain problems in collaboration with them."[24]

17. There are several techniques for refining each tool for assessment, besides the over-all aspects of its *reliability* and *validity*. Each technique has a specific purpose. There seems to be a growing interest in *factor-analysis*. There is the magical appeal of its elaborate and meticulous statistical treatment. But there is often only a vague psychological interpretation of the factors. Usually there is a dearth of interest in II-order Factors, or in oblique rotations ; although these are implicit in the basic structural hypotheses of the tests of educational aptitudes as well as of general mental ability. Much good work is being done all over the country. Its scientific level could improve with communications, through the impulse of competition and the impact of criticism. It is in this mood that I beg to place before you some illustrations of certain techniques tried in recent studies at Banaras. I also trust that these statements would induce our colleagues in other areas to exhibit their results and thus help us in enjoying the multi-faceted advance of psychology in India.

V

(b) EXPERIMENTAL STUDIES AT THE BANARAS HINDU UNIVERSITY

18. I will begin by placing before you the common handicap of *an unreliable age-record* of our school going students. This is the population most easily available to our psychological testing enthusiasts. But they are severely disappointed when average age-performances indicate entirely unexpected trends. Hence they feel that any *age-norms* for our tests of general mental ability (or intelligence) are suspect. Further, it is reasonable to assume that certain verbal elements of our tests should be somewhat influenced by the extent of a child's schooling. This would add to the influence of examination sophistication, which is also increasing in parallel with a child's experience of school examination. In short, 'grade norms' are preferable to 'age norms', in spite of the attendant risk of confusion with tests of educational achievement. But age-norms have a special value of their own. It may be noted that there is also the possibility of a *modal age* for each class (or grade), which rises in parallel with the school grades. Thus a compromise may be effected by using data from only 'modal-age-grade groups' for obtaining more reliable norms. In one study[25] we obtained the following results of age-performance for a verbal group test of general ability given to IV, V and VI form students (see Table 1): It appear's that 14 is the *age of arrest,* and 15 is the onset of the *age of decline.* These are surprising facts (!). The grade-norms seem to fare better (Table 2): The model-age-grade norms appear to be *equally good* and definitely *more* sound in theory. I have no doubt that such norms would definitely prove more useful than age-norms obtained from unreliable records.

TABLE 1—GIVING AGE-PERFORMANCE.

Age		N	Ave. Score
14—14·11	...	371	51·23
15—15·11	...	416	49·69
16—16·11	...	411	49·23

TABLE 2—COMPARING GRADE NORMS WITH MODAL-AGE-GRADE NORMS.

N	Ave. Score	S.D.	Form	Modal Age	N	Ave. Score	S.D.
789	43·78	11·58	IV	14	210	43·81	11·38
684	51·65	12·17	V	15	144	51·40	11·35
527	55·25	12·61	VI	16	148	55·07	10·07

19. Let us turn to the problem of discovering the *difficulty values* of test items through a quantitative item-analysis of passes and failures in a given sample. It is well known that many items are left *unattempted* by the students. Since all such tests are more or less time-limited ; even a liberal time allowance would not be free from importing a factor of *speed* in our data. It is further complicated with the factor of *power*. In a *pure* speed test, *e.g.* tapping, cancellation, etc., there are no errors ; and in a pure power test, each item must be attempted. But the common experience is that unless the instructions are of the 'must guess' type, some unattempted items are always included in the

data. However, instructions for deliberate guessing bring in other undesirable complications. A safer procedure is to make a somewhat stringent allowance for time, and ask the examinees to skim obviously too difficult items. This was the compromise accepted for certain tests of general mental ability during the large scale testing of army recruits during the last world war in India and elsewhere. An item-analysis for regrading the difficulty values of the given items for the Indian personnel got bogged through the upsurge of two possibilities : (1) The unattempted item is rejected after reading because it is too difficult, so it is to be put in the *wrong* category. (2) The unattempted items are rejected off-hand, without wasting any time in reading them, on the basis of known individual shortcomings, and hence it should be neglected. Here it may be noted that the statistical treatment is simplified in the former case, but it is much complicated with the latter assumption. In one of our studies, we attempted a comparison of both these assumptions. In a group of 410 cases, only 60 persons appeared to reach the last item of a 20 mt., 100 item, verbal group test (in Malayalam, 6/51). These were separated for special treatment. It was assumed that this group was speedy and possibly superior, while the rest group was representative of the general average in the said sample.* We tried both the techniques with each group. In one case,* $T=p+u+w$; and $d=(u+w)/T$...(i). In the second case, the formula was $d=w/(w+p)$...(ii). The various rank orders thus obtained were correlated by the Spearman formula, and the *rho* (ρ) was *corrected* to obtain an equivalent r by the formula : $r=2 \text{ Sin } \left(\frac{\pi}{6}\rho\right)$ The correlations are uniformly high, ranging from ·84 to ·98 (Table 3).[26] In the *smaller* group there are only a few unattempted items, and the inter-correlation of the two techniques is very high (·98). Hence, we feel justified in accepting the less laborious procedure, on the grounds of superior theoretical basis, as *u* and *w* are assumed to be equal from the point of view of *power*.

TABLE 3—GIVING CORRECTED CORRELATIONS.

N	Wrong	Group	A	B	C	D
350	u+w	A	—	·876	·865	·835
,,	w	B	—	—	·967	·953
60	u+w	C	—	—	—	·978
,,	w	D	—	—	—	—

20. Further, we commonly use a small number of test-elements, with all similar types of items either put together in a *battery* type test, or mixed together according to their difficulty values in an *omnibus spiral* type test. The *relative weightage* of the given test-elements becomes an intriguing problem. We have the procedure of the Multiple Correlations of the element-scores with the 'total *minus* the given element-score'. This is a tedious process involving the revision of the total scores for each constituent element. Hence the said refinement of technique is often overlooked in practice by less rigorous research students, and unfortunately corrected multiple R values are rare. The alternative *z*-scale technique for the sub-tests is even more frightening

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* **Let u=unattempted, w=wrong, p=pass, T=total, d=difficulty value.**

and is seldom attempted. We could however also discover the *relative discrimination value of our test elements* by taking the *top* and the *bottom quarter* groups on the basis of the total scores, and thus compare the success of these groups on the several elements. This involves only the preparation of a fresh score-record of half the population, and the results are equally informative. In one case, a group of 721 school students was thus divided and the following results obtained (Table 4).[27] Table 5 clarifies the situation by indicating the three groups of elements with *high* (33 to 35%), *medium* (21 to 24%) and *low* discrimination.

TABLE 4—COMPARING % AGE OF SUCCESS BY THE BRIGHT AND DULL GROUPS.[27]

Elements	A	B	C	D	E	F	G
Bright	60·39	73·82	55·50	32·64	65·28	43·44	46·00
Dull	39·61	40·17	31·08	15·58	31·17	21·22	10·69
Diff. %	20·78	33·05	24·42	17·06	34·11	22·22	35·31

TABLE 5—GIVING THE RELATIVE DISCRIMINATIN OF THE TEST-ELEMENTS.

	Analo.	Best Answers	Opp.	No. Ser.	Reasoning	Similars	Classification
Diff. %	35·31	34·11	33·05	24·42	22·22	20·78	17·06

21. It is to be noted that the picture of the relative discrimination of the test-elements is often complicated with the *character of the test population*. For example, in a group of selected superior Engineering students (=94), the relative discrimination value of certain test-elements differs from that of an average teacher trainees B. Ed. group (N=100), in the case of a point scale for adults in English (Table 6). Here we see that for the engineering group the discrimination ability of most elements is low. It is surprising that Best Answers and Opposites are at the very bottom ; while Analogies, Similars, Mathematical Instructions and classifications are several times superior ; and that Number Series has only 19·10% discrimination value. But the situation with the average group of B.Ed. students is very different. Here, Number Series tops the list with 51·33%, while Reasoning and Opposites vie with Mathematical Instructions. In short, the situation cannot be definitely determined by a single study with one test and a specific group. We should be cautious in our judgments. I do not think that we could simplify the situation

TABLE 6—GIVING RELATIVE DISCRIMINATION VALUE FOR ELEMENTS OF 20-52.[28]

Group	Number Series	Math'l Instr'n.	Following Instr'n.	Similars	Opposites	Classification	Best Ans.	Analogies	Reasoning
Engineering	19·10	25·17	22·57	26·86	10·29	25·10	9·72	29·39	16·25
B. Ed.	51·33	30·67	28·66	24·89	31·55	26·67	20·66	25·11	28·80

artificially by insisting with Prof. C. Spearman, on an all-round homogeneity in a test sample, but I do expect that the latitude of a large group with a fairly normal distribution would give us useful results.

22. I will now place before you another vexed problem of *item-selection*. The techniques are usually widely divergent, and often tailored to suit the different conditions. We have to do a good bit of our thinking here also. In one case, we wanted to select 10 items each of *similars* and *opposites* for the vocabulary section of a selective type verbal group test of general mental ability (in Panjabi). We took 32 items for each element through the entire range of the alphabet, with the help of a dictionary. Each item was provided with 4 alternative answers. In the preliminary study both of the elements were printed on two sides of a sheet and answers were obtained from 500 students of the VIII, IX, and X classes from a dozen schools. The item-analysis gave us the difficulty rankings for the said three classes. Now we could either pool the several values of the items, *or* select them on the basis of a single class-result. We obtained intercorrelations for the three sets of rankings. The results show quite high correlations (Table 7).[29] Now we decided to reject *too easy* items with less than the chance expectation of 25% wrong answers. We also rejected items with more than 60% incorrect solutions, as likely to prove *too difficult*. We were agreeably surprised to find 8 items of *similars* and 7 of *opposites* common to three classes within the above said difficulty range. Since the IX class rankings had higher correlations with the VIII as well as the X, then the rest ; so we decided to select the balance from among items of IX with nearabout ranks in the VII or X group. The average difficulty values of the selected items is on the easy side (Table 8). This should increase the range of scores for discrimination of the near-average students. We are inclined to believe that the fairly uniform rate of increase of the over-all difficulty in spite of continued schooling indicates that we are dealing more with a test of general vocabulary ability than of some scholastic ability. Hence, we should expect our procedure to prove justified in practice.

Table 7A & B—Giving Correlation of Difficulty for Different Classes.

	A—Similars			B—Opposites		
Class	VIII	IX	X	VIII	IX	X
VIII	—	·958	·901	—	·952	·944
IX	—	—	·941	—	—	·969
X	—	—	—	—	—	—

Table 8—Giving Average Difficulty for the Selected Items.

Classes	VIII	IX	X
Similars	48·55	44·06	41·13 %
Opposites	46·29	43·26	37·64 „
Average	47·42	43·66	39·39 „

VI

THE NEED FOR RESEARCH PUBLICATIONS

23. I have taken much of your valuable time to place before you some suggestive local studies. My only apology lies in the fond hope that such interesting but unpublished results are useful stimulants and they may go to reduce the general 'depressed feeling'. I have no doubt that most other universities in India will have even a more attractive record to show. But due to the acute paucity of scientific psychological publications in India, we often suffer the disadvantages of a *kūpa maṇḍuka* (frog in the well) existence. I am convinced that our progress in psychology will remain extremely limited, until we can remove the canker of 'isolation' and cooperate on the academic level. India is a vast country with widely separated centres of research. If some of us, even in one region, could pool together our academic resources and secure the blessings of some university willing to risk a small sum in publishing our researches ; then we could hope for encouraging recognition at home and abroad. The meagre investment of some three thousand rupees per annum by a university would bring it merit in the present and enshrine for it a glorious place in the future. It is indeed a curious anomaly to me that while our universities are eager to claim a place under the sun for their researches, they should pay only a deaf ear to the crying need for publication of research journals. In the early days of British bureaucartic stepmotherly treatment to research in India, the specialist research journals had to depend upon the unpredictable stream of individual donations for their day to day existence. But now that the Central Government of India maintains a Ministry of Scientific Research, it should not be too much to expect a generous interest in assisting research publications. This could spur the band of contemporary research workers in Psychology to redouble their efforts, and confidently look forward to a well deserved recognition of their worth in the pages of some scientific journal at home.

24. May I further point out that a sustained interest in one's research publications is a simple solution to the frustration reaction among some of our intelligent teachers, that urges them to fish in the troubled waters of *politics*(?). It seems to me that our contemporary politicians give a squint-eyed emphasis to the security and welfare of a small number of workers in "Key" ports and industries, while they have only a big blind-spot for the security and welfare of the thousands of very poorly paid members of the teaching profession. It is a pity that advance in years and experience, even for the elite only focusses attention upon the insecurity of superannuation and the instability of an unemployed future. A statutory date is indeed an entirely unsatisfactory proof that any individual is "unemployable". (It appears that one big lure of politics is its freedom from an age-bar). It would be absurd to suggest that India is so advanced in education today that she can afford the spendthrift policy towards recognised talents and also successfully aspire for an honoured place in research. There is no doubt that the wastage of ripe talents, hoarded experience and specialised critical acumen of the retiring university teachers can be easily saved by keeping them (untrammelled with administrative routine) to guide research in their specialised fields, and thus render inestimable service to the advancement of their subject and their country. All this would again underline the need for more assisted research publications in every field.

25. I am sure that I am voicing the feelings of every one present here, when I say that financially assisted publication of research journals is a crying need of psychology in India today. At the present moment we have some journals eking out a very difficult existence, the quarterly being reduced to a half-yearly, or only an annual, and even then waiting for the eccentric mercies of a publisher's leisure. Our teaching staff is too underpaid to afford the luxury of supporting a specialist research journal. The general public wants *popular* psychology, and prefers the cheap fashions of the imported salacious variety. It is only the genuine worker that withers in the chill climate of unconcern. I would humbly submit that in our *national* planning the priorities for physics and chemistry, for geology and metallurgy, for agriculture and engineering, are rendered ineffective without an adequate programme for parallel developments in psychology. *Materials* and *machines* could do nothing without the fruitful agency of skilled effort by *men*. I beg leave to remind you : "In each modern industry nowadays we have a large group of workers with varying abilities and different specializations. The coordination of their efforts, and the supervision necessary for a controlled quality of their production, gives rise to inter-personal contacts, competition and occasionally to friction and conflicts. It is essential that such sources of conflict should be discovered and nipped in the very bud. It is imperative for coordinated effort that the *morale* of the individual worker on the line and of the supervisory personnel should be as high as possible. These everyday matters of inter-personal clashes due to the over-riding necessities of *quality, production* and *wastage reduction,* form the most alluring and fertile field for the application of psychology to the problems of man-management and of industrial relations. Here too there is urgent need for a probe into the motivation of the Indian worker in the rank and file of agricultural as well as of industrial production and distribution. This is a field wherein the psychologists in India have to sow and reap harvests on their own, and their success will be commensurate with their scientific insight and the earnestness of their application."[30] Both of the latter, you will note, thrive on efficient research communications.

26. It may be added that, "planning implies a systematic selection of special aspects of production and consumption, which presumes a readiness to undergo the necessary sacrifices by every individual. The reason for our planning priorities has to be made not merely clear and obvious to the people, but it should be also made an integral part of their hiararchy of values, both economic and political, as well as social and cultural. This is a task that eminently calls for suitable propaganda for the attainment of desired psychological ends. The services of psychologists can be of immense benefit for reorienting and upgrading public morale."[31] With this conviction, I invite all of you to prepare well ahead for the multifarious tasks that cannot but be entrusted to you in a measurable future. We have much to gain from the age-old maxim : He helps those who help themselves. Hence I venture to advise my younger colleagues to look forward to the future with robust enthusiasm and an unflinching optimism.

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SECTION OF ENGINEERING AND METALLURGY

President :—DR. M. DATTA, PH.D., M.SC.TECH., M.I.E.E.

PRESIDENTIAL ADDRESS

POWER SUPPLY IN OUR NATIONAL PLANNING

LADIES & GENTLEMEN,

We meet to-day in a function of direct and intimate interest to our profession viz., Engineering and Metallurgy in our country. The General Session of yesterday was an august gathering where we invited our distinguished guests who are all worthy people of note and standing. This morning we hope to conduct the business of the day in a homely atmosphere.

I consider it a great privilege to preside over this section and I must express my deep sense of gratitude and appreciation for the honour you have done to me.

When I realised that it would be necessary for me to choose a subject for an address which should be of general interest, I found myself confronted with something of a problem. I looked back through the records and discovered that, with few exceptions, the addresses of my predecessors have been coloured by their individual experiences in the years preceding their election. No appologies are, therefore, needed for my having chosen the subject of "Power Supply in our National Planning". The importance assumed by the Planning and Development of Power in our successive Five Year Plans is unmistakable. I propose to take an overall national view of the present Power Supply position and its trend of future development. I shall try to approach the subject from a somewhat new angle, with special reference to certain selected aspects, particularly those which are now being accepted for achieving the target set before us in accelerating power development in our country.

Everything, great or small, has its phase of infancy. It appears rather clumsy and sketchy at the start, and slowly and gradually its trend, pattern and features become distinct and manifest. Power development on a national basis in our country cannot escape from this normal law of development.

Present civilisation owes its existence mainly to the utilisation of mechanical power by man. The steam engine altered the human outlook and paved the way for large-scale industrial development and during nineties of the last century it came to be realized that the main source of power for economical use at home and the industry would in course of time be electrical energy. The problems of high voltage generation and transmission of electric power from its source of production to different consuming centres has since engaged the attention of Engineers and it has been found economical in many respects.

The economic prosperity of a country is, however, judged to-day largely by the amount of electricity it consumes. The per capita annual consumption of Electric energy in India is only 25 units whereas those of the other industrially advanced countries like England and U.S.A. the present per capita consumption figures per year are 1270, and 4400 respectively—the average annual consumption of electricity per head of population for the whole world being 600. This is an indication of the leeway our country has to make up. Table—I shows Energy Consumption and Resource of India in comparison with some advanced countries of the world.

Taking a very modest target of 100 units per head per year for India for near future, it would mean that the country in order to raise its level of economic development would have to consume nearly 34000 million units a year which is equivalent to some 8,000 MW of maximum demand at about 50% load factor and would call for an installed capacity of the order of 12,000 MW.

The problem of providing power at a cheap rate has been tackled in other advanced countries by concentrating generations for public supply purposes at a limited number of selected large stations. To enable the most efficient plant to operate at its best, as well as to keep the standby to a minimum, generating stations have to be linked by means of transmission network called grid system. In consequence, the concentration of generation in large power stations and the construction of regional grids connecting them and the principal load centres by extra high voltage lines are in the forefront of India's plans.

SOURCES OF ENERGY

Sources of energy may be grouped under two headings—non-replenishable and replenishable. Non-replenishable sources comprise coal and oil in which energy has been stored in the distant past. This energy can be used at any desirable rate until the supply becomes exhausted.

Although the tidal, wind, solar power and the natural heat of earth have been used on a small scale as sources of energy in some parts of the world, the power obtained from them is fortuitous and hardly economic for large scale production. Hydro power resulting from falling water is the only replenishable source of major importance. Such water power sources are being continuously replenished usually by the action of sun. This energy can be used continuously at a daily or yearly rate corresponding to the rate of replenishment. In India we are very well placed in regard to water power potential which has been estimated to be of the order of 40,000 MW (Table—I).

Indian resources of economically transportable low grade coal as distinct from metallurgical coking coal which is both in short supply and required exclusively for steel industries have been estimated at 40,000 million tons. Taking about 3 tons of coal per 1KW year, it should be possible to achieve an average out-put of more than 27 million KW over a period of about 500 years.

Semi-bituminous and anthracite coal fulfil the requirements of power generation most satisfactorily although quite low grade coal can be effectively burnt. Transport of such coal to the generating stations would be a problem. Hence, mine-head power stations have become very economical and eminently suitable for the loads of Bengal-Bihar Coal field areas.

Power is also being produced from nuclear energy. Basic nuclear fuels are uranium and thorium. India's west coast is famous for its deposits

TABLE 1

ENERGY CONSUMPTION AND RESOURCES

Country	Energy Consumption				Non-replenishable energy resources					Replenishable sources	
			Electric consumption		Capital sources—Million Kwh.					Hydro	
	Population 10^6	Total consumption Million kwh/year	Total Million kwh/yr.	Kwh per head/yr.	Coal	Peat	Oil	Oilshale	Natural	Potential in MW	Installed in MW
India	361	1200,000	9,100	25	1800×10^6	—	—	170×10^3	—	40,000	800
Britain	50	1750,000	64,000	1,270	290×10^6	13×10^3	—	—	—	500	370
U.S.A.	123	8800,000	544,000	4,400	2230×10^6	40×10^6	220×10^6	620×10^6	105×10^6	100,000	18,000
U.S.S.R.	193	4400,000	166,000	860	2900×10^6	230×10^6	272×10^6	$2{\cdot}5 \times 10^6$	10×10^6	60,000	1,700
France	41	590,000	41,000	1,000	$42{\cdot}5 \times 10^6$	$6{\cdot}5 \times 10^6$	100×10^3	$2{\cdot}5 \times 10^6$	—	4,500	4,500
Norway	3·3	100,000	22,000	6,600	—	—	—	—	—	7,500	2,900

TABLE 2

CHARACTERISTICS OF GENERATING PLANT

	Conventional	Nuclear	Gas Turbine	I.C. Engine	Hydro	Tidal	Wind	Solar
Capital cost—Rs./KW ...	1000/-	2500-4500/-	1000/-	1000/-	1000-2000/-	1500-3000/-	1000/-	6000/-
Running cost—np per kwh.	2·5	2·0	3·0	6·0	0·5	0·5	0·5	0·5
Output kwh/year/KW ...	8000	8000	8000	8000	1000-8000	5000	3000	2000
Availability %	80-90%	80-90%	80-90%	80-90%	10-90%	30%	20%	20%
Usual type of load ...	Base	Base	Peak or Standby	Peak or Standby	Peak or base	Fortuitous	Fortuitous	Fortuitous
Time to start	2-3 hrs.	2-3 hrs.	15 min.	10 min.	10 min.	10 min.	10 min.	10 min.
Response to varying load ...	Poor	Very poor	Good	Good	Very good	Very good	Fair	Fair
Location	Influenced by fuel, cooling water	Influenced by safety consideration & cooling water	Any where	Any where	Topographical	Topographical	Topographical	Sunny climate
Size of unit	Upto 300 MW	Upto 100 MW	Upto 50 MW	Upto 10 MW	Upto 100 MW	Upto 100 MW	Upto 1 MW	Upto 1 MW
Waste	Ash and flue gas	Radio active products	—	—	—	—	—	

of monazite sand. Cakes containing uranium and thorium are now being produced in India. It is estimated that the deposits of nuclear fuel could meet the demand for power for 1500 years. It is probable that nuclear power stations will be put in hand in India on commercial scale before long but as on present indications the overall cost per kwh will be appreciably higher than in the case of conventional coal burning or Hydro Station. Moreover, to operate nuclear stations economically and efficiently a high load factor is essential and we have to defer construction of nuclear power stations on commercial scale until our grid and inter-connectors grow more extensive and flexible.

Table—I amply illustrates how favourably India is placed compared to other advanced countries of the world in respect of her water power potential and coal reserve.

From the Table—II illustrating the relative economics of different sources of power, it may be concluded that we must rapidly develop our untapped hydro resources backed by coal fired power stations. In India the capital cost per KW of installed capacity for small and medium sized hydel power stations have more often than not been relatively higher than that for comparable thermal power station. But most of the large hydro-electric projects currently under execution and planning and also the future ones envisage to generate large amount of power and the capital cost involved in their implementation is quite competitive with and in many cases even lower than those of comparable pit head coal fired power stations. Besides, the longer life of the works, plant and installation of a hydro-electric project together with lower running cost results in lower overall cost of generation of hydro power. A matter of decisive importance on which the prevailing shortage of foreign exchange focusses attention, is that whereas the investments on thermal schemes comprise a very high proportion of foreign exchange (since bulk of the cost is on plant and equipment which have to be imported) the investment on hydro schemes, being largely on civil works the foreign exchange component of capital cost for hydro-power station plant and equipment constitute a much smaller fraction of the total capital expenditure.

It is, therefore, obvious that for a considerable period emphasis shall be on pit-head coal-fired thermal power and hydro stations all over India except for a few nuclear power stations in places far remote from coal reserve and water power sites because of its locational flexibility and/or for experimental purposes in regional grids where sufficient base load is available.

ZONEWISE REVIEW OF POWER DEVELOPMENT

The present and future trend of development of hydro and coal-fired power potential of India are illustrated in the map with eight well-marked regions (Fig. 1). In the background of overall national economy in the development of power all over the country, it has been recognised that the distribution of natural resources of power generation and the scope of utilization of power do not conform to the political divisions of the country into the various states. To secure optimum development and utilization of power potential All India Power Engineers Conference at Bangalore in January, 1957 have emphasised the need for co-ordinated planning and development of power on Zonal basis. In consideration of the concentration of hydro power potential resulting from the different mountain ranges it has been found apt and appropriate to name the different power Zones after the respective mountain ranges to which their hydro potentials are due.

The Power Zones are:—(1) Southern-Western Ghat, (2) Northern-Western Ghat, (3) Eastern Ghat and Godavari Valley, (4) Satpura, (5) Western Himalayan, (6) Central Himalayan, (7) Eastern Himalayan and (8) A Zone comprising Assam, Manipore, Tripura and NEFA. The last Zone does not go by the name of any one particular mountain ranges as their scattered hydro power resources are to be attributed to different mountain ranges. Nevertheless, this Region may well be regarded as a power zone by the distinction that it stands apart from the rest of India in almost geographic and economic isolation.

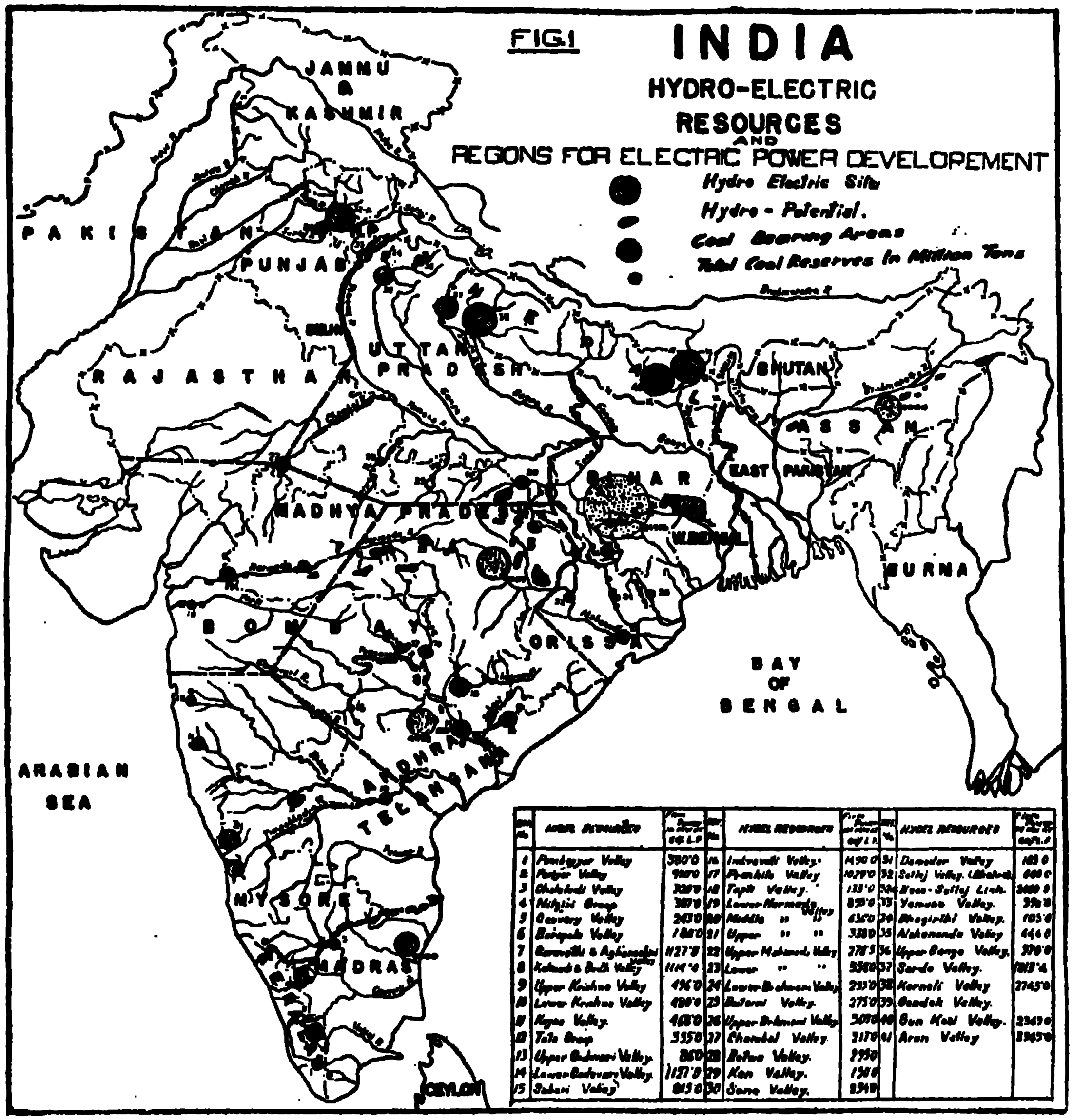


FIG. 1 INDIA HYDRO-ELECTRIC RESOURCES AND REGIONS FOR ELECTRIC POWER DEVELOPEMENT

Sl. No.	HYDEL RESOURCES	[illegible]	Sl. No.	HYDEL RESOURCES	[illegible]	Sl. No.	HYDEL RESOURCES	[illegible]
1	Pambayar Valley	380·0	16	Indravati Valley	1490·0	31	Damodar Valley	189·0
2	Periyar Valley	920·0	17	Pranhita Valley	1029·0	32	Sutlej Valley (Bhakra)	600·0
3	Chalakudi Valley	328·0	18	Tapti Valley	135·0	32A	Beas-Sutlej Link	2000·0
4	Nilgiri Group	387·0	19	Lower Narmada Valley	850·0	33	Yamuna Valley	396·0
5	Cauvery Valley	243·0	20	Middle " "	436·0	34	Bhagirathi Valley	105·0
6	Bairapale Valley	188·0	21	Upper " "	338·0	35	Alaknanda Valley	446·0
7	Saravathi & Aghanashini Valley	1127·0	22	Upper Mahanadi Valley	278·5	36	Upper Ganga Valley	570·0
8	Kalinadi & Bedti Valley	1114·0	23	Lower " "	558·0	37	Sarda Valley	1813·4
9	Upper Krishna Valley	496·0	24	Lower Brahmani Valley	233·0	38	Karnali Valley	2745·0
10	Lower Krishna Valley	498·0	25	Baitarni Valley	275·0	39	Gandak Valley	
11	Koyna Valley	408·0	26	Upper Brahmani Valley	507·0	40	Sun Kosi Valley	2343·0
12	Tata Group	355·0	27	Chambal Valley	317·0	41	Arun Valley	2345·0
13	Upper Godavari Valley	86·0	28	Betwa Valley	295·0			
14	Lower Godavari Valley	1127·0	29	Ken Valley	150·0			
15	Sabari Valley	815·0	30	Sone Valley	254·0			

Zone—1 : This Zone comprises the States of Madras and Kerala. Both these States have so far proceeded on hydro power development except for the city of Madras. Important hydro stations in the Zone already in operation and under implementation are—Pykara, Moyar, Mettur, Papanasam, Periyar, Pallivasal, Paringalkuchu, Sengulam, Neriamangalam and Peniyar. Madras city thermal station has also been extended by installation of another 30,000 KW set. The projected 250,000 KW thermal power station on lignite mines of Neiveli has opened new possibility of low cost thermal power generation in the Zone. The large hydro power potential in the southern portion of Western Ghat in this zone can be harnessed in mutual collaboration of the two States, thus offering the possibility of development of a regional grid in this Zone which is already in the offing. This Zonal grid also holds prospect of inter-connection with Zonal grid in Mysore bulk of whose future requirement of power will be derived from proposed Sharavati Hydro-Electric project. The aggregate installed capacity in this Zone at the end of first plan period was 261,200 KW and is expected to be 10,10,000 KW at the end of second plan period.

Zone—2 : This Zone comprising the entire States of Mysore and Southern portions of Bombay and Andhra is also predominantly a hydro Zone. The important power stations already in operation in this Zone are the thermal power stations at Chola, Trombay, Hyderabad and Nellore and the hydro stations at Bhira, Khopoli and Bhipuri of Tata Power Co. The important hydro power sources in this Zone are—(1) Koyna (408,000 KW), (2) Kalinadi and Bedti (11,14,000 KW), (3) Sharavati Aghanashini (11,27,500 KW), (4) Upper Krishna (4,96,000 KW) and (5) Lower Krishna (4,80,000 KW). The first stage of Koyna project already under implementation under SFYP envisages the installation of 4 Nos. 60,000 KW sets. Tungabhadra Project jointly undertaken by the Governments of Mysore and Andhra with an installed capacity of 20,000 KW will be completed within second plan period. The most important project undertaken by Mysore Government is Sharavati Valley project with two units of 89,100 KW each initially under SFYP increasing progressively upto the ultimate total installed capacity 891,000 KW. The Bhadra Project envisaging to have an installed capacity of 33,200 KW is also under implementation under SFYP. The Bombay-Poona area in this Zone has tremendous load potential which will have to be catered initially by harnessing the resources of Koyna and thereafter by implementing the Kalinadi group of schemes which being situated in the enlarged Mysore State will have to be implemented jointly by Bombay and Mysore to their mutual benefit. The long-term planning for power in Bombay-Poona area would also call for large-scale generation of power from nuclear resources as this area is far removed from coal reserve. The installed capacity in this Zone at the end of first plan period is 580,000 KW and that at the second plan period is expected to be 1,070,000 KW.

Zone—3 : This Zone comprises the North-Eastern portion of Andhra, Eastern portion of Bombay and major part of Madhya Pradesh. The hydro power potentials in the Zone are mainly concentrated in the Godavari and her different tributories aggregating 4,400,000 KW. There are two major coal fields in this Zone viz. Singareni in Andhra and Korba in Madhya Pradesh offering possibiity of development of large-scale thermal power development. Hydro power sites so far developed in the Godavari basin is that of Machkund with an installed capacity of 51,000 KW under First Five Year plan which is now being extended to its full plant capacity of 110,000 KW under second Five Year plan. Besides, the first phase of Sileru project envisaging an installed capacity of 120,000 KW is already under execution under SFYP. This project has a potential under the upper and lower stages of the order of 800,000 KW capable of both economic and rapid development to meet the potential demand in the Zone. The important thermal stations in operation and under implementation in this Zone are those at Khaparkhada (20,000 KW) and Korba (90,000 KW). There is also a proposal for a 60,000 KW. thermal power station at Birsingpur in this Zone. The load growth in this region has been somewhat poor so far but holds forth possibilities of rapid increase in future years which will call for harnessing the hydel power potential of the Godavari basin and also large pit head thermal stations in Singarani and Korba coal field area. The installed capacity in this Zone at the end of first plan period was 352,000 KW and that at the end of the second plan period will stand at 693,000 KW.

Zone—4: This Zone comprising the Northern portion of Bombay, Western portion of Madhya Pradesh and Southern portion of Rajasthan has a total hydro potential of only 1,895,000 KW and has no coal field. Power development in this Zone has hitherto been based on thermal generation inspite of the fact that this area is very remote from the collieries of India. The important thermal power station in this Zone is that at Ahmedabad. There is no hydro power station in operation in this region. Of the total hydel power potential of 1,895,000 KW in Narmada, Tapti and Chambal basins only the last one having an aggregate potential of 217 MW is going to be harnessed to the extent of 92,000 KW initially under first stage under SFYP as a joint venture between the Governments of Madhya Pradesh and Rajasthan. The Punassa Project with a power potential of the order of 450,000 KW in the Narvada Basin is being actively considered for meeting the load demand of Northern Bombay and Western Madhya Pradesh and when implemented would set the pace for further power development in this region. The installed capacity in this Zone till the end of first plan period was 238,000 KW. and that at the end of the second plan period will be about 422,000 KW.

Zone—5: This Zone comprises the major portion of Rajasthan, Delhi, East Punjab and Himachal Pradesh. The major hydro power stations already in operation in this Zone are:—Jagindernagar on Beas (48,000 KW), Gangwal (48,000 KW) and Kotla (48,000 KW) on the power canal taking from the Nangal barrage on Sultej river. This Zone is also remote from the coal field. The major thermal power station in this Zone is that at Delhi (62,000 KW). The entire hydro sources of power in this Zone lies in the north. A beginning has been made under the Bhakra Project envisaging to generate 600,000 KW at 60% load factor under SFYP. These vast resources and its large network of transmission lines will establish their sphere of influence extending through the States of Panjab and Pepsu, upto Delhi and Rajasthan in the south and into certain areas of Himachal Pradesh in the north. The demand of power beyond the scope of the Bhakra Project in this Zone will have to be met by extension of Delhi thermal power station and also by further hydro development in the Beas Valley. Diversion of Beas water into the Sutlej basin behind the Bhakra reservoir will afford sufficient power to sustain the rapid pace of load development in this Zone. The power potential of Beas basin has been estimated at 2000,000 KW.

The installed capacity in this Zone at the end of first plan period was 232,000 KW. and that at the end of second plan period is expected to be 900,000 KW.

Zone—6: This Zone comprises the entire portion of Uttar Pradesh and Northern portion of Madhya Pradesh. This Zone has a total hydro power potential of 27,45,000 KW of which 7,90,000 KW lies in the Karnali basin, 18,15,000 KW in Sarda river, 5,58,000 KW in Yamuna and 1,05,000 KW in Upper Ganga basins. There is no coal field in this Zone. The hydro power development in this Zone so far are the seven power stations on the Ganges canal aggregating about 48,000 KW of installed capacity and Sarda (40,000 KW). Work is now in progress on Rihand project where two units of 50,000 KW each are expected to be commissioned by 1960-61 and 3 more units of even rating will be installed shortly thereafter. Investigation is in progress on second stage of Yamuna (150,000 KW) and Ramganga (75,000 KW). The major thermal stations in this Zone are those at Kanpur (80,000 KW) and Hardwarganj (20,000 KW), Construction of Power stations at Garakhpur (10,000 KW), Mau (10,000 KW), Sohowal (10,000 KW) and Manipuri (10,000 KW) has been completed to provide power for tube-well. Work on additional generating units of 5,000 KW each at the first three thermal power stations is in an advance stage and is likely to be completed by 1958-59. Augmentation of Harduarganj thermal station by installing 2 Nos. 30,000 KW sets is in progress. One more 15,000 KW set at Kanpur thermal power station is likely to be commissioned by early this year.

The installed capacity in this Zone at the end of the first plan period was 350,000 KW and that at the end of the second plan period is expected to be 670,000 KW.

Zone—7: This important Zone with vast industrial potentialities comprises West Bengal, Bihar and the majort part of Orissa above the Mahanadi river. The central and southern part of this region are rich in resources of coal and other mineral resources viz. iron, mica, copper, bauxite etc.

Progressive growth of thermal plant installations at Calcutta (435 MW) constituted major power development in this region till the post-war period when Damodar Valley Project covering the southern portion of Bengal and Bihar and Hirakund Project in Orissa were taken up. Uptil now 214,000 KW of installed capacity of D.V.C. is in operation of which 150,000 KW accounts for the installed capacity in Bokaro thermal station and 64,000 KW for hydro installations in Maithon and Tilaya. Programme of power development of D.V.C. under SFYP includes extension of Bokaro thermal station by one 75,000 KW set, construction of a 150,000 KW thermal station at Durgapur and installation of a 125,000 KW set at proposed superthermal station at Dugdha and installation of a 40,000 KW set at Panchet dam site power station. West Bengal Government is building up one 60,000 KW thermal power station at Durgapur and a 18,000 KW hydro power station in North Bengal on Jaldhaka river. Bihar Government is building up one 30,000 KW thermal power station at Barauni under SFYP. In Orissa under the first stage of Hirakund Project an installed capacity of 123,000 KW at the main dam has already been commissioned. Implementation of the second stage which envisages the construction of the Chiplima power station (72,000 KW) at the end of the power channel from the main dam and also the installation of another 37,500 KW set at the dam site power station under SFYP is already in progress.

In Bihar and West Bengal which have plentiful sources of coal, thermal generation forms the main-stay of its current development. Future development in the southern and central portion of this Zone is expected to be based on the utilization of hydro resources of the southern Zone and on the thermal generation to the extent necessary. The hydro power potential in the southern portion of this Zone are those of lower Mahanadi (558,000 KW), Lower Brahmani (255,000 KW), Upper Brahmani (509,000 KW) and Baitarani (275,000 KW). The Bhimkund Project on the Baitarani has already been investigated and the project report prepared for inclusion under Third Five Wear Plan period to meet the growing load demand of Orissa and D.V.C. area. As load demand increases, the utilization of hydro power sources in the Himalayan range will naturally have to be considered. The major water power sources due to eastern Himalayan range in this Zone are those of Kosi (4,725,000 KW), Gandak and Tista (9,48,000 KW).

The installed capacity in this Zone at the end of First Five Year Plan was 12,07,000 KW and that at the end of the second plan period is expected to be 19,45,000 KW.

Zone—8: This region comprising the contiguous States of Assam, Manipur and Tripura can be considered as a separate unit for planning. Power development in this Zone is in a nascent state and consists of isolated small-scale development. The Zone abounds in natural resources and power development at potential centres can advantageously be initiated by small and medium scale schemes. The Umtru Hydro-electric Project with an installed capacity of 8400 KW commissioned in 1957 is one such. Under SFYP a thermal station of 6000 KW will be installed at Umtinagar. About 1700 KW of plant is expected to be added by small schemes included under rural and small town electrification schemes. This Zone possesses vast resources of hydro-electric potential, but these resources have yet to be surveyed. On a very rough estimate the power potential of the Zone has been estimated to be of the order of 13,270,000 KW.

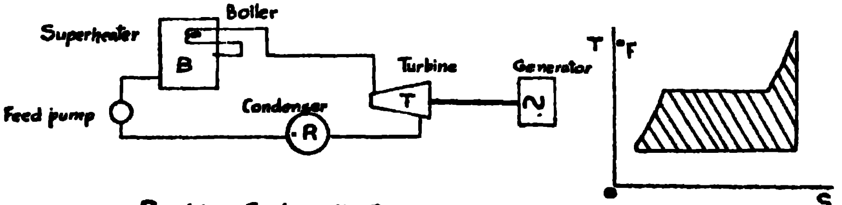
PRESENT TRENDS IN STEAM POWER GENERATION

The inter-connection of large power stations and formation of different regional grids during the post independance period has led to the adoption of higher rating of turbine and alternator for reasons of overall economy in respect of capital as well as maintenance and operational expenditures. The sizes of turbo-alternators now being installed in India in the different major power stations feeding the different regional grids ranges between 30 and 75 MW. The projected thermal power station of Damodar Valley Corporation at Dugda will have the largest set in India viz. 125 MW. Thermal conditions of the steam of the sets being installed at present is considerably in advance of those of previous sets. The turbine inlet steam condition at Bokaro thermal power station commissioned in 1952 is 850 lbs/sq. in. and 900° F as against 1450 lbs/sq. in. and 1000° F. of 75 MW set now being installed at D.V.C.'s Durgapur Power Station.

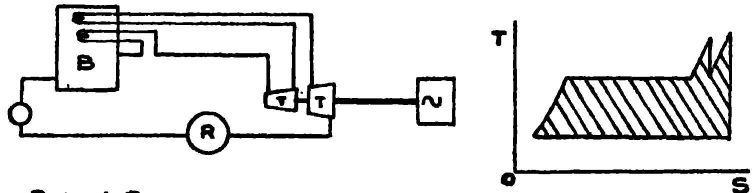
During the last decade considerable investigation has been carried out in order to establish in practice the thermal gain from a change in steam cycle. Use of Rankine cycle with Super-heat to prevent condensation during passage through turbine or Reheat cycle to avoid excessive moisture without having a high initial temperature are now greatly influenced by the metallurgical improvements which enable very high initial steam temperature. A recently projected 275 MW set has a pressure of 5,000 lb/sq. in. and initial temperature of 1200°F. with two reheats to 1050°F. (Philadelphia Electric Co.). Majority of modern high efficiency plant use Re-generative cycle by bleeding steam from one or more points as it passes through the turbine and using this steam to heat the feed water.

Though the use of field cycle is in the experimental stage it has great possibility as it is claimed to give better efficiencies than regenerative cycle at high temperature (overall values of about 45% is claimed for 1050° F). Exhaust steam from turbine is used to supply super-heat. The dry saturated steam leaves the compressor and is partially superheated by the exhaust and further by fuel fired super-heater. The steam then passes through the turbine which it leaves at a high temperature and flow through the regenerator and back to compressor (Fig. 2).

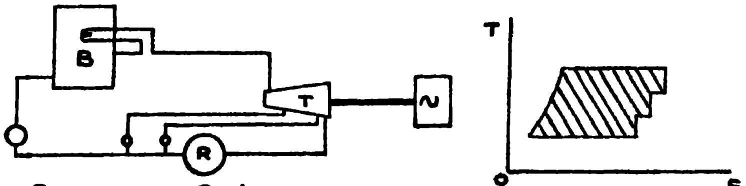
In this country where vaccum condition is lower than that in cold countries, single cylinder sets upto 50 MW have been adopted. Two-cylinder 1,500 lbs./sq. in. 100 MW turbines have been built with three bearings and rigid coupling with high pressure and low pressure cylinder to achieve optimum size. Three-cylinder sets with double flow exhaust for 900° F. and 1500 lbs/sq. in. steam are available for still higher rating. The cylinder design with either double or triple flow exhausts have been developed for very large reheat machines.



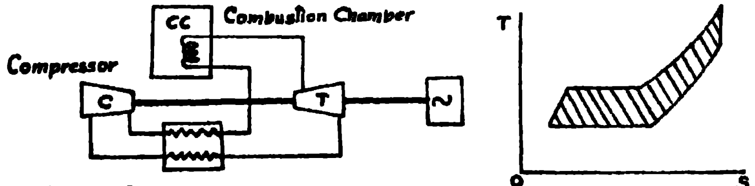
Rankine Cycle with Superheat



Reheat Cycle



Regenerative Cycle



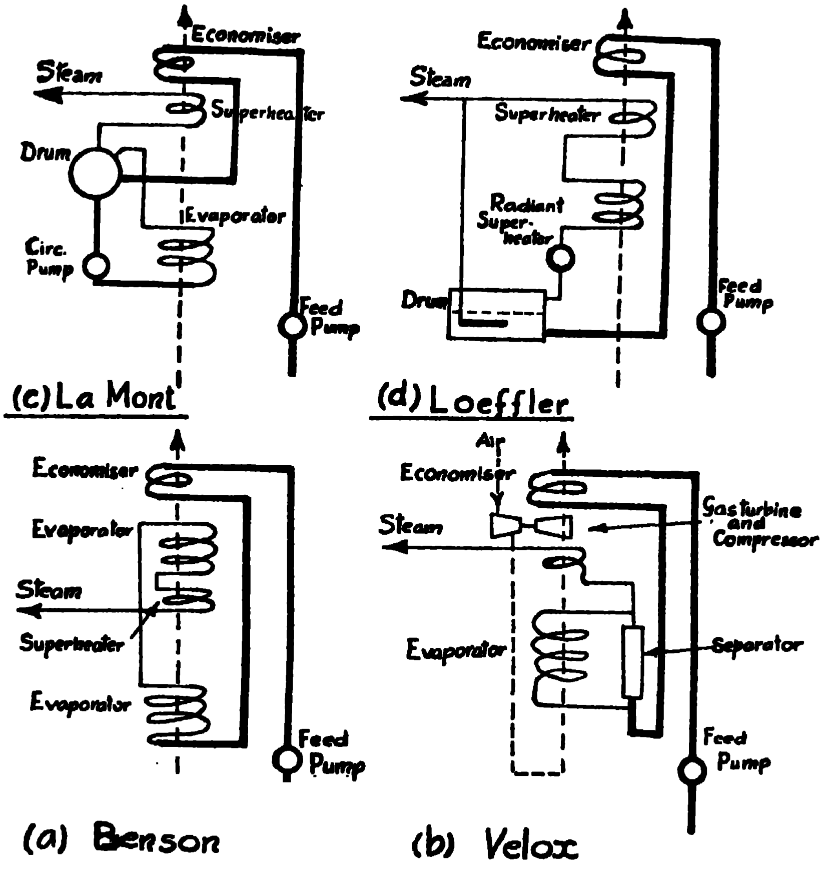
Field Cycle

FIG. 2

200 MW tandem compound turbines for steam condition of 2400 lbs./sq. in. 1050°F with reheating steam are already being manufactured for British system. Design for 275 MW tandem and 550 MW cross compound units are being examined in detail, while application with initial steam pressure beyond 3000 lbs./sq. in. are in course of development.

The air cooled generator is no longer an accepted practice for large unit. Hydrogen cooled machines were going into service with hydrogen pressure upto 30 lbs./sq. in. The Hydrogen cooled units of D.V.C. at Durgapur Power Station shall be using a pressure of 30 lbs./sq. in. Recent developments in the use of pressurised direct gas cooling of the rotor winding and pressurised liquid cooling of stator bars enable, for example, a 200 KW generator to be built with a rotor of almost same dimensions as of a 60 MW generator of early post war design.

Turbovisory instruments are now provided for all large sets to record and observe shaft eccentricity, differential expansion between turbine *and* cylinder, shaft speed etc. Nearly all plants will now operate at 3000 R.P.M. and 1500 R.P.M. plants will become increasingly obsolete as the inherent advantage of high spindle speed is to reduce plant size and initial cost.



Special Boilers

FIG. 3

Boilers :—The conventional boilers for a modern power station comprise a combustion chamber with coal or oil firing (stoker or pulverised fuel fired) from which hot gases pass through suitably disposed heating tubes steam drums, economisers, air-heaters, super-heaters, reheaters etc. Normal rating is 300—600 Kilo lb./hr. The largest boilers in use in India at present are at Trombay having a capacity of 600 Kilo lb./hr. The boiler unit of Durgapur will be of 730 Kilo lb./hr. out-put.

Boiler combustion technique is now considerably advanced. Majority of boilers having evaporative capacity above 300 Kilo lb./hr. are now-a-days pulverised fuel fired. The chain grate or spreader stokers are limited to 150-250 Kilo lb./hr. out-put. Dry type furnaces which is suitable for any type of coal is now-a-days giving place to slaggging furnace producing hard granular ash which can be easily disposed of as an industrial material suitable for building and road construction. Slag furnace can now be designed to burn coals of much higher ash fusion point. The development of cyclone furnace for burning of high ash content low fusion point coal for stoker fired boiler and its adoption to p.f. firing gives high rate of melting. 70% to 80% fly ash could be melted by cyclone firing as compared to 40 to 50% by conventional firing in slagging furnace. So far as part load behaviour is concerned such furnaces are satisfactorily operating upto 40% of load and even lower. Slag type furnace has made rapid strides and majority of continental boilers above 150 Kilo lb./hr. are equipped with such furnace. A mechanical and electrical dust extractor with p.f. boilers have proved very successful. Water level is now-a-days televised and remote controlled sequence operated soot blowers have become a part and parcel of large boilers.

Special Boilers: Various special type of boilers have been devised to generate steam of very high temperature and pressure for quick starting. All employ forced circulation of water enabling smaller tubes, quicker starting and less troubles from scaling. (Fig. 3).

Benson Boiler has no drum. The water is evaporated in main tubes and then super-heated. It was originally designed for a pressure upto 3,000 lb-/sq. in. but is now being built for conventional range of pressure too. It can raise steam nearly at the rate of 550 Kilo lbs./hr. at a subcritical pressure. It can be started in about 15 minutes.

On the continent of Europe a number of Velox Boilers and power plants are in operation in steel industry. These boilers are very useful as standby plant in hydro electric stations. It is designed for pressure combustion in a combustion chamber where pressure is maintained at 35 $\mathrm{lb./in.}^2$ by an air compressor. The compressor is driven by a gas turbine supplied with furnace gas. A 10 Kilo lbs./hr. unit can be brought from cold to full pressure in about 4 minutes.

In Loeffler Boiler a turbine driven feed pump circulates the steam through super-heater. Sudden demand for steam could be met by increasing the speed of pump. Lamont Boiler is a forced water circulation boiler where circulation can be increased upto eight times the out-put. A 220 Kilo lb./hr. boiler can raise steam from cold in 12 minutes and from warm standby condition in 4 minutes.

The availability of modern boilers is very high—being as high as 90% for mediocre grade coal. This is quite comparable to turbine availability and has led to the popularity of unitisation of Boiler-Turbine thus resulting in considerable simplification and economy in pipe work and valve arrangement.

Regarding cooling tower, an important annexe of steam power station, R.C.C. hyperbolic type is becoming very popular in India due to the scarcity of cold clear circulating water. The size of cooling tower is increasing with the capacity of power station and cooling tower as high as 200 ft. has already been built in India.

PRESENT TRENDS IN HYDRO-GENERATION

The design of hydraulic plant has gravitated more towards the adoption of large out-puts concentrated on one shaft and turbines upto 150,000 BHP or more have become current practice, if other conditions permit. In India the largest unit so far in operation is 37,500 KW at

Hirakund. Some of the hydro-electric power stations now under implementation will have units of still higher rating viz. Bhakra with 90,000 KW unit with heads ranging between 515 and 275 ft., Koyna with 60,000 KW unit at 1,500 ft. head and Rihand with 50,000 KW with heads ranging between 250 and 143 ft.

Under conditions of varying loads and heads, the automatic adjustment of runner blades angles is of paramount importance for achieving high efficiencies over wide range and to have freedom from cavitation and vibration. At present, adjustable runner blades for use upto 200 ft. head is available. Advancing scheme and research work in the field of hydro dynamic problems will probably succeed in the future to increase the working pressure limits for feathering propellors much higher.

In high heads ranging between 600 and 6,000 ft. the Pelton or impulse wheel type turbine was almost exclusively used till a few years ago. This high pressure field is now invaded by reaction turbines either of horizontal or of vertical type for operation upto about 1,400 ft. head. The application of judicious designs with the use of appropriate high tensile and stainless steel have permitted the adoption of much higher speed for both turbines and generators resulting in higher efficiency and compact plants.

Important strides have been made in Europe in the domain of harnessing of low heads by means of Axial Flow Turbines. The most remarkable development is the design of the so called "Micro Power Stations" provided with Bulb Units having induction Generators rotating in oil.

This development permits the harnessing of head drops which would otherwise be beyond the scope of economical generation. These units possess a lacuna that they cannot be utilized in isolated networks. Nevertheless, where there exist powerful electric grids, the plethora of falls all over India could be tapped in order to augment India's power resources.

These units will certainly have a greater role to play once India completes the formation of the zonal grids.

Still another new design has been put forward for low heads having a horizontal turbine of the Kaplan type and a conventional Generator lodged in an upstream pier. The Generator rotates at a higher speed as compared to the turbine, thanks to the presence of the speed multiplier. This unit offers considerable economy as compared to conventional plants.

Some plants are completely and some partially arranged underground in India but advantage of greater effective use of available head and saving in steel and penstocks have to be carefully weighed against costs of underground construction work on pressure shafts, access tunnels etc., since under conditions obtaining in India, these can be considerable.

There are two less well known forms of water power viz. pumped storage and tidal power projects. They can assist steam and hydro-electric stations in difficult periods of heavy demand and can utilize energy which might otherwise have been wasted in tidal or 'run-of-river' hydro-electric station during light load periods. In France, a single basin ebb tide working tidal station on the Rance has started functioning. But a tidal scheme would be economic only if the cost of tidal energy absorbed by the system were less than the price of coal delivered to the station. But such possibility is extremely remote in India.

Although there are many economic and other problems, associated with the effect of pumped storage on thermal plant operation, it is safe to conclude that with an appropriate choice of load factor and capital investment approaching that of an equivalent steam station, the rapid availability and ability to meet unexpected plant break-downs or demands would make pumped storage worthwhile and might reduce the cost of producing electrical energy from the system as a whole. There are two types of installations for this purpose, one where turbines and pumps are independent and the latter is driven by the reversible for pumping purpose. We have scope for pumped storage in many of our large multipurpose projects.

Comprehensive automaticity which is very much in vogue in modern large power plant is also being introduced in India to enhance the safety factor. This is necessary as continuous concentration on proper supervision for day and night service in isolated localities is difficult. Such automaticity comprises opening of valves, priming of pressure ducts, checking of bearing and cooling systems, starting of governor gear, release of brake, synchronising and loading up. The reverse cycle should safely provide against normal and emergency shut-down, run away and all electrical failures.

PRESENT TRENDS IN TRANSMISSION AND DISTRIBUTION

As the electric power supply industry grew the technology of transmission improved and developed. The progress of generation has been a fairly continuous process but the development in transmission was spasmodic.

The most obvious application of H. V. system is in the transmission of bulk power from a hydro-electric station or from a large aggregate of thermal generating plants on a coal field to the load centre for consumption or to inter-connect power stations to reduce total amount of standby plants.

In India problems arise and will continue to arise from transmission of large blocks of power over large distances. Stability and line regulation will in these cases be the criteria of design so that it will be common to find extensive use of synchronous condensing plant in our future regional grids.

Choice of Voltage: The Engineers charged with the responsibility of developing system at minimum cost generally hesitate to take any ambitious step for developing high voltage network as it involves large initial capital out-lay.

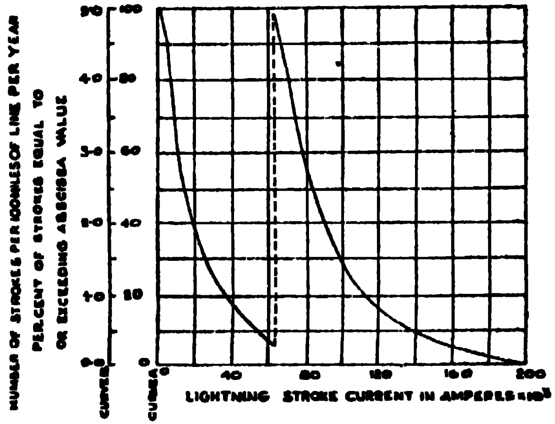
In the great majority of H.V. systems of our country the design is considerably influenced by past developments as future possibilities are far from clear. Hence, two courses are open, one being to extend whatever systems already exist and the other being to provide for a new system of higher voltage. Short-term planning will ideally suit the former with the result of congested development ; whereas a long-term planning (which is considered essential as the demand of power in this country is expected to double in 5 to 6 years for a considerable period from now onward) leads to 2nd course involving considerably heavy initial capital expenditure but will pay in the long run.

A ratio of 2 for the voltage of new system to old system was frequently adopted in this country in the past but such low ratio does not suit satisfactorily the paralleling of systems owing to the reactance of the intervening transformers. Experience shows that a ratio of 3 or 4 will suit our country satisfactorily.

132, 110, 66, 33, 11 and 6·6 KV lines have so far been extensively used in this country. The selection of one of these preferred standard voltages for a new installation is desirable for India.

With regard to the choice of voltages above 200 K.V. the voltage level is basically guided by the availability of accepted designed plants as the curve of the cost of transmitting a given amount of power for such voltages varies only very slightly with the voltage level. Sweden which is most advanced in H.V. transmission system has 1000 miles of 400 KV line carrying several thousand of mega watts. Plans are being made these for an A.C. system at about 600 KV. In India 220 KV lines are being erected.

Insulation Level: For entirely underground system the insulation level is dictated by the switching surges whereas for overhead lines both lightning and switching over-voltages will occur. Lightning tends to produce voltages almost independent of system voltages whereas switching surges are generally proportional to the system voltages. So far as switching surges are concerned a maximum of 4 times the normal phase to neutral peak voltage has been experienced in inductive circuits such as idling transformers, but with regard to the ampitudes of lightning surges it is very difficult to predict. Statistics of the magnitude of stroke current and its frequency distribution are now being collected by different supply organisations over this country. The average earthing resistance in a particular region may be easily determined and hence from frequency curve the number of strokes that will produce voltages in excess of design values may be calculated. (Fig. 4).



LIGHTNING-STROKE CURRENT PROBABILITY CURVE

FIG. 4

Thus one approach to the choice of insulation level is now-a-days to select an impulse level related to nominal peak voltage by a factor exceeding the highest switching over voltages expected and then to determine the probable lightning faults for such an insulated system. If this number is too high the insulation level must be raised or the nominal voltage of the system should be increased to take advantage of the increased insulations.

Good results have been obtained by shielding sub-stations and part of adjoining lines with over-head ground wire and co-ordinating the insulation level at the entrance of sub-station with the terminal plants.

Regarding the basic insulation level for different standard transmission voltages, there is a tendency in America to reduce it in effectively grounded system. In such systems a protective level of 80 or even 75 per cent of American standard value can be obtained with modern lightning arresters, and the insulation level of high voltage equipment can, therefore, be reduced to the same extent.

Switchgear: Very considerable progress has been made during the post-war years in the design of high voltage switchgear in technically advanced countries.

Increased short circuit capacity breakers at 132 KV is available upto 5,000 MVA and for 220 KV system 15,000 MVA breaker with rated breaking current of 33,000 A.

Out-door 132 KV Air Blast Circuit breakers were recently introduced in this country. Previously majority of designs incorporated radial flow interruptor while the latest design provides for axial flow interruptor exclusively. The increased length and weight of the insulator necessitate the use of tubular porcelain instead of cap and pin type insulator.

In some of 132 KV and 33 KV systems small oil volume circuit breakers are being used. Since in this type of breaker the arc control device is enclosed in minimum amount of oil, there is less fire-hazard. This point has always been exaggerated though there have been very few fire-hazards with bulk oil type which are still in use in large numbers in the country with very good service record.

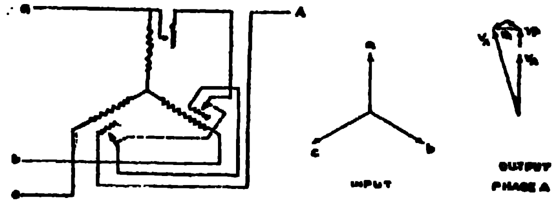
Most of the 66 or 132 or 220 KV circuit breakers are now-a-days provided with automatic reclosing device inspite of the fact that there is always a risk of about 25 per cent of the cases of reclosure being unsuccessful due to persistent fault and such condition always leads to greater disturbances. The reclosure should be very rapid and generally recloses after a dead time of say 8—10 cycles.

In modern Power-stations the 11 KV circuit breakers are exclusively of air break type. The space factor is better because air breakers could be stacked in double or even in triple tiers. The general trend so far as in-door type distribution circuit breakers are concerned is towards the increasing use of vertical isolation.

So far as 11 K.V. rural distribution is concerned fault currents are generally very low and pole mounted circuit breakers with auto-reclosing devices are generally used for teeing off. In order to obtain cheap protection H.V. fuses are used extensively, liquid and expulsion types of fuses being used quite satisfactorily where short circuit current is low.

Transformers: Transmission transformers do not normally operate on continuous full load and substantial economy could be derived in capital outlay by utilizing fully the thermal capacity of transformers to meet the daily peak load. The practice is fast becoming current in U.S.A. also in Britain not to accept the name plate rating of transformers as anything but a basis of calculating allowable loading conditions. The development of cold-reduced, grain oriented, electrical sheet steel allow increased flux density for a given core size and thereby proportionate increase in rating for the same weight could be achieved. Nitrogen atmospheres are also being introduced. This permits higher winding hot spot temperatures and hence greater KVA ratings for certain weight of material ; it also reduces acidity to a negligible proportions because of exclusion of oxygen from the oil. The availability of excellent range of surge divertors accurately co-ordinated with impulse strength of the windings and closely coupled to the bushings instead of being near the line terminals has permitted reduced insulation reinforcement. Improved design technique aided by the availability of better quality steel has caused reduction of 20% iron losses and 15% in the copper loss since 1949. Transformer ratings which were considered a few years ago as impossible to make and transport as three phase units are now very common.

To control distribution of power between parallel circuits coupled by transformer the use of in-phase taps for voltage regulation is ineffective. Quadrature booster is necessary for such purpose. There appears to be certain amount of technical shyness about the use of quadrature booster in this country which are transformers with winding capable of transferring voltage from phase to phase (Fig. 5).



(a) CONNECTIONS FOR PHASE A (b) VECTOR DIAGRAM

TYPICAL BOOSTER FOR IN-PHASE AND QUADRATURE CONTROL

FIG. 5

The successive five year plans of India will necessitate a great increase in number of sub-stations, both in rural and urban areas and hence the role of distribution transformers will be ever increasingly important in cost of distribution of electricity. The Indian manufacturers should immediately in collaboration with different supply organisations agree to a standard specification for distribution transformers as such introduction will lead to repetitive manufacture of transformer to standard design and will thus reduce the manufacturing time cycle to lower the unit cost.

Copper wire or strip with the coating of Polyvinyal acetal are being introduced in the manufacture of distribution transformer in place of paper covered wire or strip for better winding space factor leading to reduction in weight of steel and copper. The use of Silicones as insulating material and mechanically joined pressure connections are expected to greatly reduce the cost.

The electronic digital computor is being used to arrive at optimum transformer designs to satisfy the manufacturers' techniques and customers' specifications quickly thereby reducing the cost of product. India should not lag behind in this respect.

Relaying and Ultra rapid reclosing: It is surprising that it takes a long time to obtain general acceptance of idea that relaying and switching have more to do with the determining of how many and what kind of transmission lines are needed to deliver a specific block of power than size of conductor and other physical characteristic of transmission line. The function of a relay-breaker combination is to disconnect the line in trouble as quickly as possible to arrest even small dimension of damage and then to reclose with minimum possible delay perhaps so fast that no effect of interruption could take place.

To match circuit breakers having a total break time of about 3 to 5 cycles, the application of protective equipments are limited to carrier current equipment (a) either phase comparison or impedance measurement principle, (b) impedance distance relays coupled with intertripping by means other than carrier current and (c) balanced protective devices for paralled feeders. Carrier current protection using the phase comparison method can provide very rapid simultaneous operation of the circuit breaker for a length of line between 20 and 100 miles. Below 20 miles, pilot wire protection is often cheaper and above 100 miles the problem of charging current and signal attenuation become difficult.

During recent years there have been no outstanding changes in the basic principle or method of operation of distance protection, but there have been lot of improvement in the design of relays. Where carrier protection is not economically justified 3 zone distance protection with various refinements to maintain stability during phase swinging is in common use in conjunction with slow speed protective devices like induction relays for back-up or directional purposes.

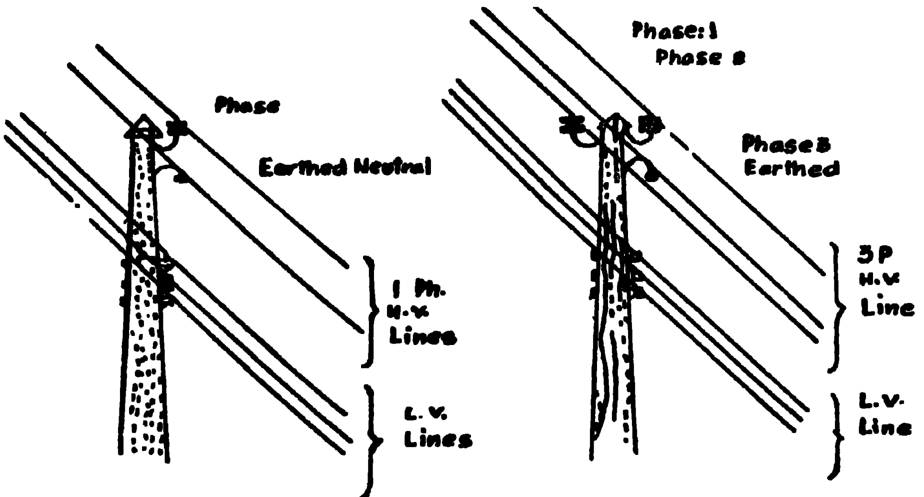
Where possibility exists such as one line connecting a hydro-generating station to its system, single pole switching with high speed reclosure may be explored, otherwise if the major portion of the load is disconnected the generator will speed up rapidly not to permit high speed reclosing. But under single phase to ground fault the stability can be maintained if only faulty phase is tripped and reclosed by necessary phase selector relaying equipment. For any other kind of fault all the phases tripped but not reclosed.

Rural Electrification :—While speaking of rural electrification in many parts of India it is worth mentioning that so long it was the practice to select the more remunerative here and there and to electrify them piece-meal. Though economically attractive from a short-term view, it entails moving of construction staff unnecessarily over the same region at frequent intervals. But considering that we are embarking upon large-scale electrification it is felt that a complete survey should be undertaken on the regional state board basis. It may be divided into several sections and mileage of mains required for each section may then be assessed. Each section could be given figure of merit represented by the number of premises which could be connected for each mile of mains. Section could then be selected in order of this figure.

Economy in rural electrification is an absolute necessity and so use should not be less than 4 for normal everyday condition and that the medium voltage lines without the use of guard wires. For limited amount of medium voltage line aluminium conductor is being used in place of copper and the use of steel conductor for some of the single phase high voltage spurs is being introduced. (Fig. 6A). Electricity supply lines may be allowed to follow the same route where telephone lines exist and vice versa. Joint construction or use of poles owned by one of the two parties viz. Electricity Board and P & T Telephone lines will render rural electrification economically feasible.

The loading conditions in our country are less severe than in Britain and there is also less difference between loaded and unloaded conditions. The present method of calculating the factor of safety of lines assuming worst wind load to occur at minimum temperature when the conductor stress is high, is very uneconomical. Considerable economy may be effected in the capital cost by adoption of the modification discussed in the Author's article published in Electrical Review May, '51. The apprehension that vibration would result due to higher tensioning of the line is unfounded as with the span lengths used for 11 KV construction no trouble due to vibration has been reported. It is recommended that F.S. should be made as much as possible of the same pole to carry high and tension during the worst load condition should not be more than 60% of ultimate strength. The worst load condition for each zone should be prescribed by an official regulation having reference to actual climatic condition. The normal every-day condition for West Bengal for example may be taken as 90°F. without wind.

For rural distribution choice of protection is limited by economic consideration. Co-ordinated use of an autorecloser with fuses gives satisfactory result. (Fig. 6b) The conventional co-ordinated circuit recloser are generally 'look-open type'. (Fig. 6c) The other type which has great prospect in this country is 'hold closed' recloser which operates very



COMBINED H.V./L.V. OVERHEAD LINE CONSTRUCTION

FIG. 6a

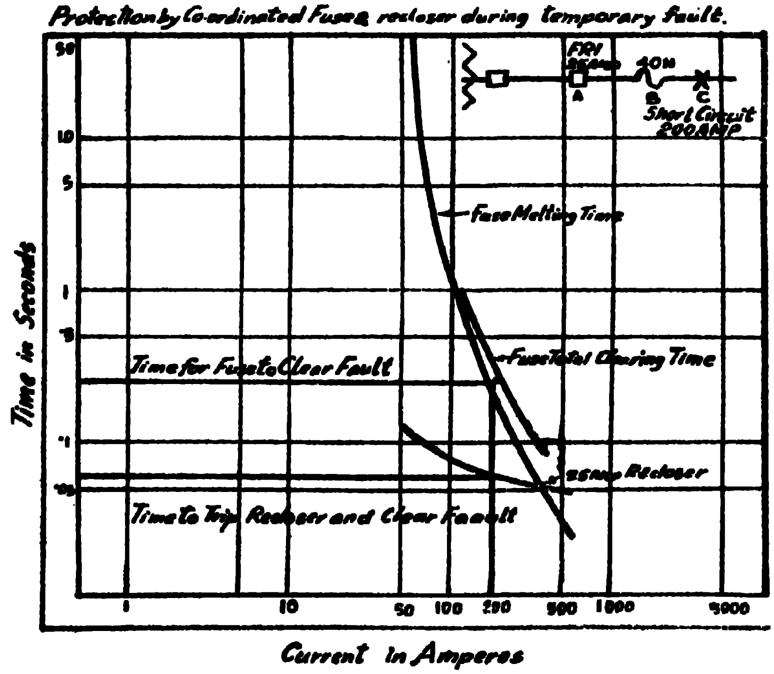
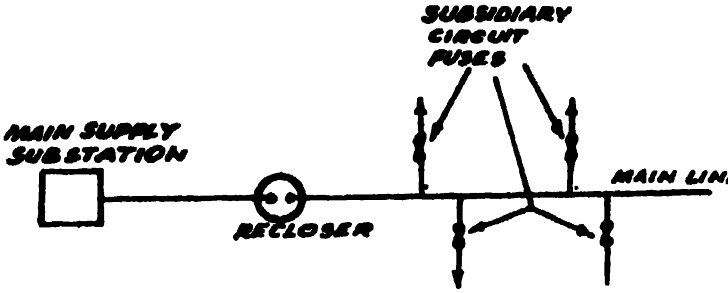

Protection by Co-ordinated Fuse & recloser during temporary fault.

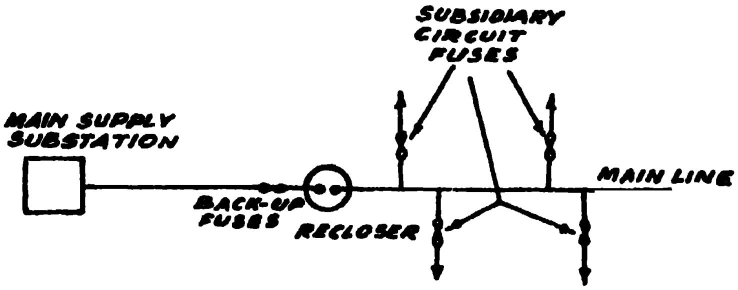
FIG. 6b

rapidly to clear a temporary fault before the fuse can blow and then holds closed when proper fuse clears the fault. This type of recloser is capable of withstanding temporary abnormal current due to pick up of load after shut-down which may be sufficient for 'look open type' recloser to open (Fig. 6d)



Recloser of the lock-open type installed in the main supply network with subsidiary lines fuse protected

FIG. 6C



Recloser of the hold closed type installed in the main Supply network with back-up fuse protection. Subsidiary Circuits fuse protected.

FIG. 6d

Communication :—Carrier current telephony on power line for communication have been in use in power system for the past quarter of a century. The success of carrier in communication has introduced its use in telemetering and in control purposes too. Though carrier current now supplies a basic demand very satisfactorily for high voltage network, yet because of the crowding of frequency-spectrum it will have application restricted to feeders, the field of principal transmission will perhaps be invaded by a system of micro-wave. Mobile maintenance units and Portable Walkie-talkie units have become very useful for maintenance work.

STABILITY AND IMPORTANCE OF NETWORK ANALYSER

In India where large hydro schemes have to be developed with long transmission line, the problems of system stability should require careful study.

The design of long distance transmission system is greatly influenced by voltage drop and synchronous stability. For all lines above 150 miles for 132 KV and 200 miles for 220 KV for our country should be initially checked for stability of synchronous machines connected at both ends.

Reactance compensation with synchronous condenser or by shunt capacitor has now been frequently adopted in our country as the transmission of vars required by the load and consumed in the inductive plant usually adversely affect the load carrying capacity of line. Reactance compensation with series capacitor seems to be a very useful means of improving system stability. The active length of line so far as power frequency is concerned is shortened by the insertion of series capacitors. The development of the series capacitor was retarded for a long time in India as well as in other parts of world due to scarcity of long lines. It is still difficult to provide adequate protection for such capacitor against voltages associated with fault currents. Synchronous machines run satisfactorily in parallel as long as they can exchange sufficient power to correct any phase swinging that may take place between them due to any change of load or other disturbances. As regards transient stability it is not the critical angle which counts but the most important factor is critical fault duration curve which must have to be solved with the help of a network analyser.

The use of Network analyser is imperative for the design and planning of our power system. It is effectively used for the study of problems associated with Loading, Fault, Stability and High frequency transient. It is a most difficult and strenuous proposition to solve complicated problems analytically without the help of a Network analyser. Changes of load, alteration of transformer tappings, modification of reactive control by the application of synchronous condensers, the effect of outages of lines or plant are few of many investigations that could be carried out in detail. An operating condition is frozen on the analyser set up for each of the conditions of interest and a record is made for voltage and power for each case.

Studies to determine the maximum and minimum currents and voltages under conditions of fault which are essential for the application of circuit breaker and protective devices could however be easily carried out on a simple D.C. network analyser with sufficient accuracy for all practical purposes. But the scope and accuracy of such analyser are limited.

The limits of stable operation under steady condition are determined on A.C. network analyser by increasing the loading in steps thus stretching the network until it reaches the limit of synchronism. In a multi-machine system the power/angle relations are complex and the problem of stability is checked by increasing loading in such a way that angles between machines are not widely separated to get out of synchronism. The determination of steady state limit is usually of less importance than that of transient limit i.e. the limiting power that can be transmitted without synchronism being lost when a fault is successfully cleared. The usual procedure is to plot swing curves or angle/time curve to determine whether the machines swing back in a steady state following a disturbance.

These curves require to be studied step by step on a A.C. network analyser augmented by necessary analytical calculations to include the effect of inertia of machines as it is not possible to correctly represent inertia and time factor on a static type of A.C. network analyser.

The transient network analyser which is broadly similar to the static type A.C. network analyser but is designed to have sufficient accuracy over a wide range of frequency, is extremely useful to determine level of insulation and to choose over-voltage protective devices for any system and greatly influence the design of circuit breakers and other plants. Normally the design of miniature apparatus to fulfil this function justify a separate installation but recently British E.R.A. has designed an analyser operating at about 1·5 Kilo Cycles to carry out both functions. This is reasonably accurate for a range from 150 cycles to 10 Kilo cycles. This is sufficient for the study of circuit breaker restricting voltage transients and that of lightning by changing the frequency scale. The total number of A.C. network analyser in the world is about 50 of which 4 or 5 are in Britain. In India we have only one. It is highly desirable that we should have few more analysers of modern types operating at higher frequency.

PROSPECT

In a review of this nature an attempt is usually made to forecast what the future has in store. Prior to independence electric power generation was confined only to some remunerative urban and industrial areas. With the initiation of successive Five-Year Plan programmes, the importance of electric power for an all-sided and balanced economic development of the country has been duly recognised.

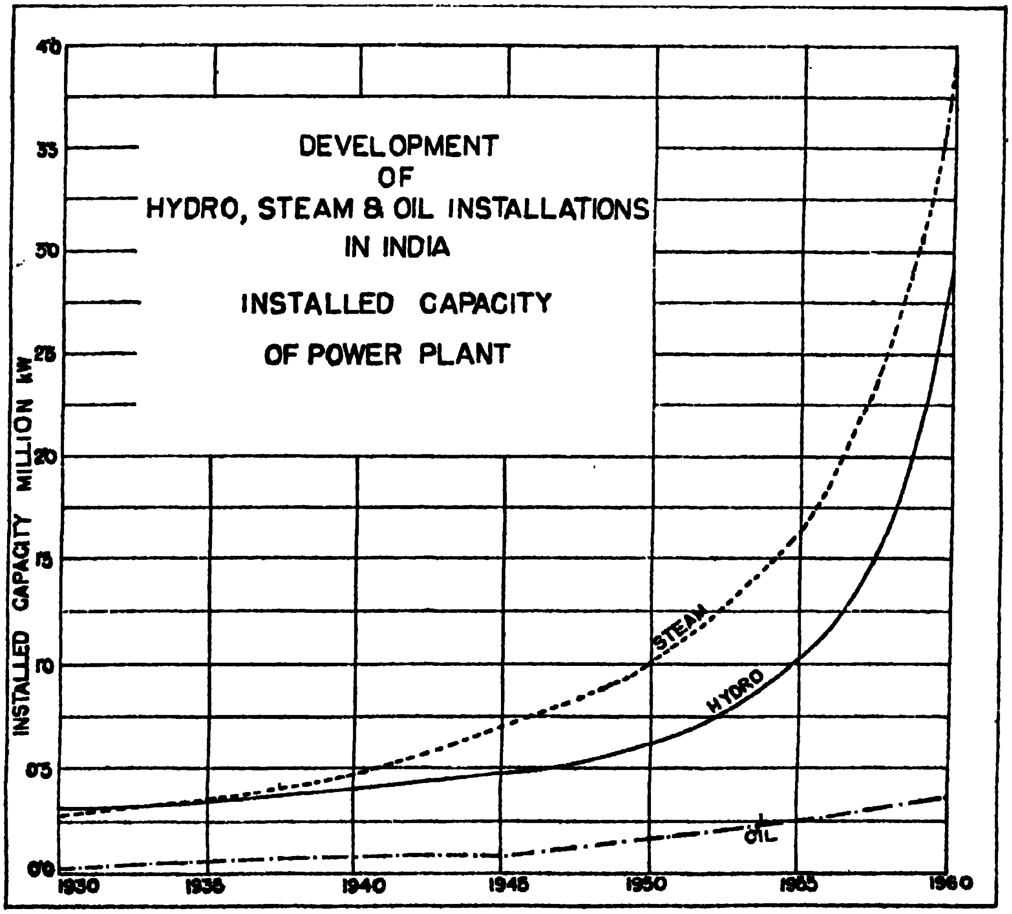


FIG.7

At the beginning of the First Five-Year Plan the total installed generating capacity of power plants in the country was 2·3 million KW. During the First Five-Year Plan period 1·1 million KW plant was added bringing the total installed generating capacity including the installation in the self-generating industries to 3·4 million KW. at the end of the first plan period. The target under SFYP is to increase the installed capacity by 3·4 million KW bringing the generative capacity to 6 million KW at the end of the plan. (Fig. 7 & 8).

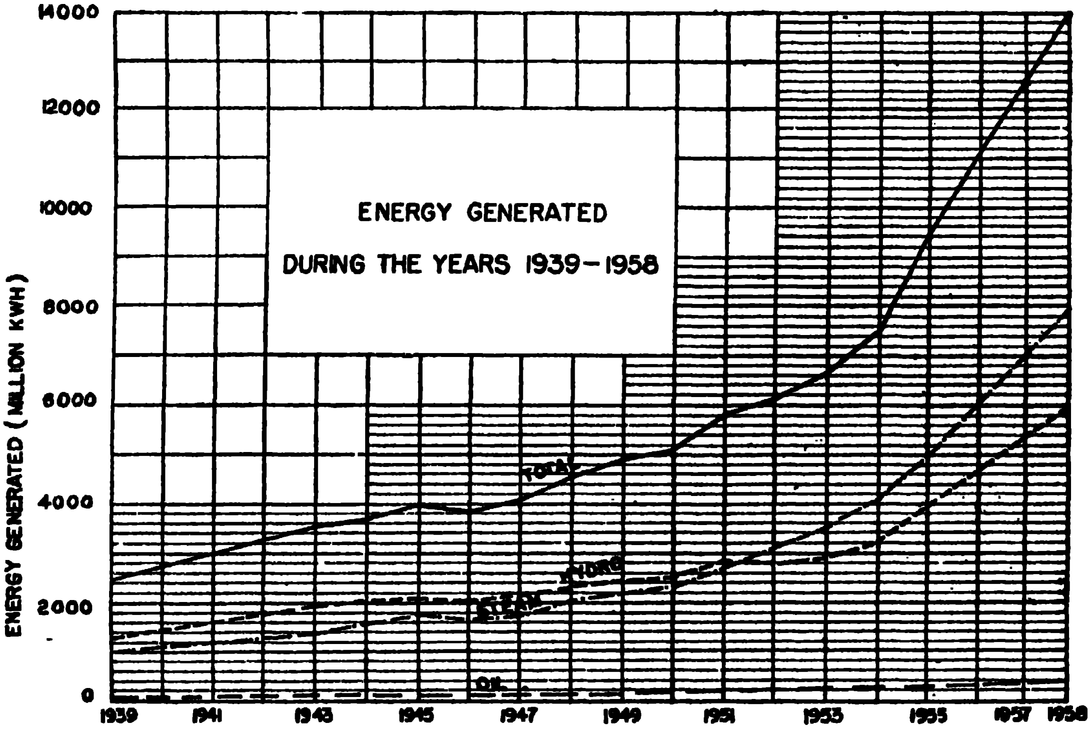


FIG. 8

The growth of power consumption and its pattern are largely determined by the tempo and pace of industrialization. The most remarkable thing about electric supply is the way in which load had doubled itself over and over again in periods of time which has seldom been longer than 7 to 8 years in most advanced countries. (Fig. 9). The present rate of growth of power consumption in our country is of the order of 10 to 12 per cent. But in view of rapid industrialization, the Planning Commission consider it realistic to provide for an annual increase in demand of power at 20 per cent upto the end of third plan period. The question is how long this increase will be maintained. There is, however, no definite sign of saturation as yet in sight and my opinion, however, is that it is still a long way off. The rate of load doubling every 7 years would mean doubling of the network every seven years which would also mean facing the problem that the next 7 years we have to build as much as has been built over all the years to date. But the lower voltage network will remain substantially unchanged and is made to carry more and more load by introducing injecting points at every decreasing distance. Most of the development that has taken place, therefore, is primarily the development of higher voltage network.

The 132 KV grid which is regarded as a power transmission system in this country as a whole, may have to be regarded as much more a distribution system as time goes on aided by introduction of higher voltage network of which 220 KV is the next prospective voltage for use of transmission system. Indeed the connection of power station direct to 220 KV network will soon be realised and in a decade or so if large generating power stations continue, and I think they will, all important power stations will take very little note of the existance of 132 KV network unless completely automatic generator working from nuclear power make local generation economic. But it is difficult at this stage to foresee anything that could vastly affect the upward trend in the adoption of higher and higher voltage.

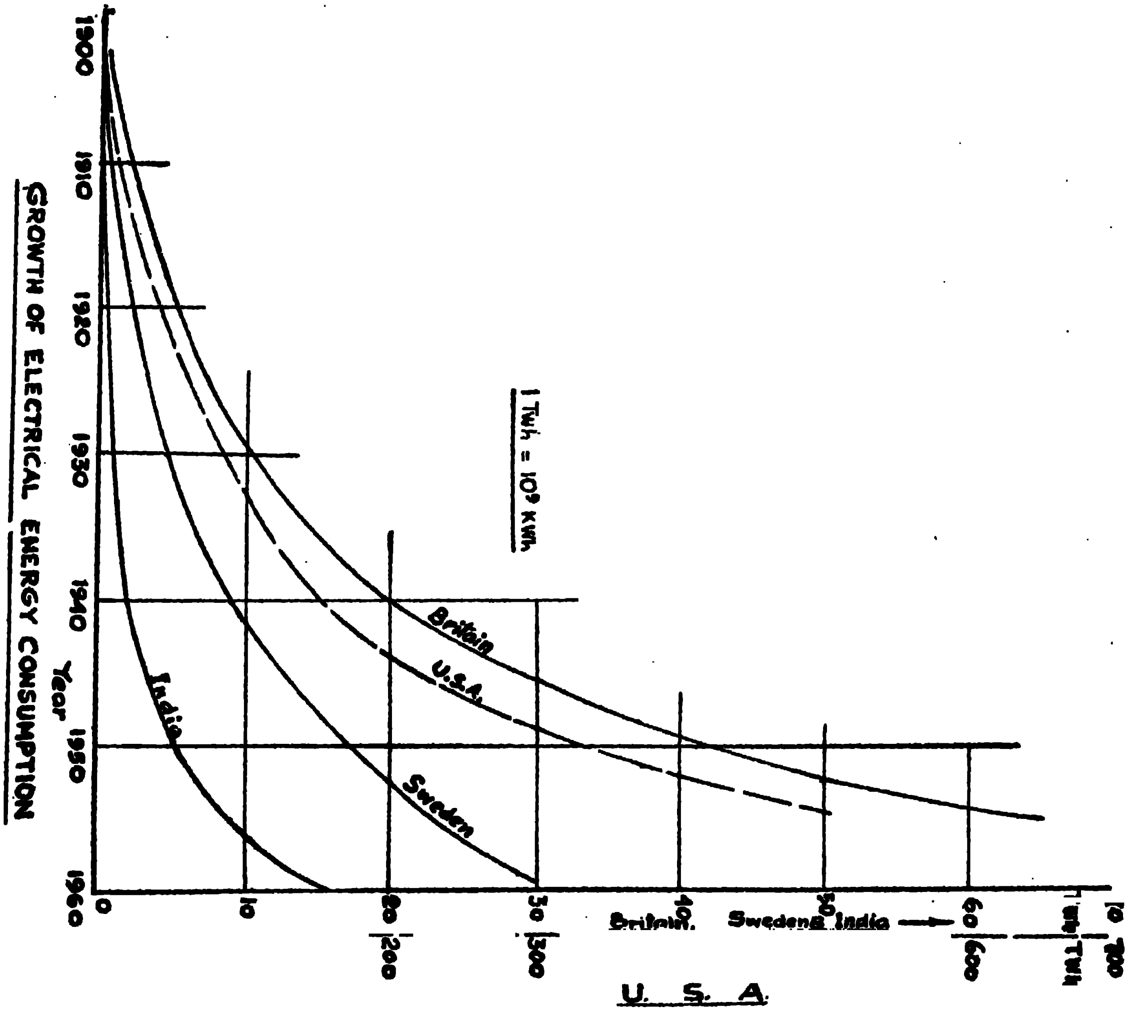


FIG. 9

So I conclude with the thought that power supply and distribution will continue to grow and expand. Those who are engaged in the field of Power Engineering can rest assured that the future holds much in store to keep them interested. Power Engineering is not the exclusive role of Electrical Engineers. Civil, Mechanical Engineers, the Metallurgists all will have to act in concert and co-operation to make our to-day' dream into realities of to-morrow.

My friends permit me to thank you all again.

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30th	„	1943,	Calcutta	19	8	0
31st	„	1944,	Delhi	18	0	0
32nd	„	1945,	Nagpur	18	4	0
33rd	„	1946,	Bangalore	21	4	0
34th	„	1947,	Delhi	23	2	0
35th	„	1948,	Patna	23	0	0
36th	„	1949,	Allahabad	21	12	0
37th	„	1950,	Poona	23	12	0
38th	„	1951,	Bangalore	27	12	0
39th	„	1952,	Calcutta	32	6	0
40th	„	1953,	Lucknow	36	0	0
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